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STUDENT RESPONSE.

BY R. L. SACKETT,
President of the Society.

We seem to be especially pestered to-day by that age-old query "Is youth demoralized?" The volume of the wail means little. Age is like that! Only at present it seems to be worse. The quality of our young people is determined to a large extent by the character of their parents and teachers and if youth is worse then it follows that their mentors are also evolving downward.

The fact is that students are responsive to wise teachers just as they have been since the day of Socrates. It is not our students only but ourselves that we need to examine—a task that no psychological test will do for us and an academic degree does not ensure the possession of those qualities that inspire the confidence of the student.

Personal influence is not necessarily an attribute of learning but a quality of character. Fine, ripe scholarship is a great asset, an almost indispensable one for an outstanding teacher but it is not a substitute for personality. We have not sought learning too much but we have worshipped at the shrine of character too little.

When we wail at the low standards of alumni and students, we also are charging ourselves with negligence and are confessing that we have underemphasized the importance of high leadership when training teachers and when engaging them. Knowledge of the art is no substitute for character and bemoaning present-day morality is no atonement.

There is a great and growing demand for engineers who are *leaders* and the demand is equally insistent that they shall be men of ability and of character. We have many wise teachers in our colleges and universities but we need more good *leaders* in our colleges and universities and students are keen to hear them.

THE SUMMER SCHOOL FOR ENGINEERING TEACHERS *

SESSION OF 1927

PART IV. SELECTED ADDRESSES AND PAPERS

HISTORY OF MECHANICS BEFORE NEWTON

By E. W. Rettger

(Presented at the Cornell Session on July 8, 1927)

Almost any article on technical education emphasizes the need of more cultural studies. Life cannot be measured in pounds per square inch, nor in elongation per unit length. The quality of a musical note depends not only upon its fundamental tone, but also upon its overtones. To bring out the overtones in life, is largely the purpose of cultural studies, and of all the cultural studies there is none, in my opinion, that is of greater value than the study of history; not the history of battles, but the history of the development of great ideas.

We are interested in the science of mechanics and it seems desirable to devote a little time to the history of mechanics. In the short time allotted, we are compelled to limit ourselves to a brief discussion in chronological order of the most important events in the development of mechanics. Those who are interested in this matter are invited to inspect several volumes placed on the reserve shelves. These books may be read with interest and profit during leisure hours.

At the start we must distinguish between mechanical experience, as Mach calls it, and the science of mechanics. Mechanical experience is very old. Consider, for instance, the ancient Egyptians, say 6,000 years ago. They left us no treatise on mechanics. From pictorial representations on tombs it is evident, however, that they used many kinds of mechanical contrivances, some of which are exceedingly ingenious while others are very crude. From these pictorial representations it appears that they used the lever for lifting heavy weights. But it hardly seems possible for them to have

* Concluding installment.

performed such remarkable engineering feats as the construction of the pyramids without suitable mechanical devices besides the lever. The Pyramid of Cheops was built about 5,600 years ago. It is 482 feet high and its base covers 13 acres. If the bottom of this pyramid were on a level with Lake Cayuga, its top would be on the same level as the top of this building (Sibley Hall). This pyramid is solid and is made of large stones, the largest weighing about 100,000 pounds. These stones were taken from quarries on the other side of the Nile. This remarkable engineering feat was performed in thirty years. How did they do it? We do not know. They must have used machines or mechanical devices of which they left us no record. Again, take the statue of Rameses II. This statue is carved out of a single stone weighing about 1,000 tons, or two million pounds. This stone was taken from a quarry some distance up the Nile. How did they move this stone and set it up? We do not know. The handling of such a stone would be a huge undertaking with all the modern equipment of engines, derricks, jacks, etc. In the walls of the temple at Balbec there are stones weighing about 1,200 tons. If one of these huge stones had to be transported on modern freight cars it would take a train of twenty-five to thirty cars to carry it. Without the use of jacks, it may be doubted if to-day a stone of such magnitude could be moved, lifted, and accurately put in place in a building.

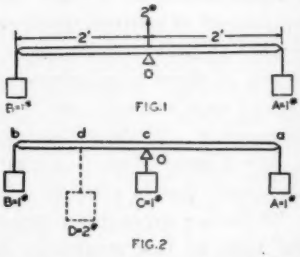
There is a great difference in using a machine and knowing the laws of this machine. A boy, for instance, may use a lever for moving a heavy weight and yet not know the law of the lever. It is generally agreed that the mechanical contrivances and devices of the ancients were the result of experience, and that they had no knowledge of mechanics as a science in the sense the term is used to-day.

Toward the beginning of the Christian era, it is known that there were in use the lever, the inclined plane, the crank, the roller, the pulley, the screw, the wheel, the cogwheel, and the wedge. These simple machines were used in a variety of ways. There was at hand then abundant material for the study of the science of mechanics.

The history of science is largely the history of a few men. This is not to be understood as meaning that nothing was done by others. The discovery of an important truth is usually the result of the investigations of many men, each of whom adds his little mite. It is left, however, to relatively few men to make the big discoveries in science, or clearly to state the important truths underlying the discoveries already made. That is, the different stages in the development of a science may be thought of as culminating in or as represented by relatively few men.

Archimedes (287–212 B.C.)

So far as is known, the first to be successful in the study of any of these simple machines was Archimedes, who derived the law of the lever and should therefore be considered the founder of the science of statics. He begins with the assumptions that equal weights placed at equal distances from the fulcrum will balance, and that if equal weights act at unequal distances from the fulcrum, the one placed at a greater distance will sink. In explaining his method of reasoning, we shall use modern terms, such as the pound and foot instead of the terms used in his day.* Imagine then two one-pound weights, *A* and *B*, placed at equal distances, say two feet, from the fulcrum of a simple lever. Neglect the weight of the lever. The two weights, *A* and *B*, will balance each other, and the reaction at *O* will be two pounds acting upwards. Now imagine a one-pound body, *C*, suspended from a point immediately above the fulcrum. This will not affect the equilibrium. The two equal weights, *B* and *C*, may be replaced by a single weight of two pounds placed at *d*, the center of the arm *bc*. That is, a one-pound weight, *A*, placed two feet from the fulcrum, *O*,



* See Mach's *Science of Mechanics*, translated by T. J. McCormack.

will balance a two-pound weight, *D*, placed one foot from the fulcrum. In a similar manner Archimedes takes up different combination of weights and finally deduces the law of the lever which he states in the following form:

> *Commensurable magnitudes are in equilibrium when they are inversely proportional to their distances from the fulcrum of the lever.*

Centuries later Galileo, Lagrange, and Huygens took up the lever, but they added nothing that is essentially new.

It should be remarked that Archimedes assumes the principle of the center of gravity of bodies as applied to two equal weights. That is (Fig. 1), he assumes that the resultant of *B* and *C* is *D* acting at the middle of *bc*. It may be added that we are indebted to Archimedes for the notion of center of gravity. Archimedes also investigated fluids and should be considered the founder of hydrostatics.

Leonardo da Vinci (1452–1519)

The next notable achievement in the science of mechanics was made by Leonardo da Vinci, who gave us the law of statical moments. Let *OA* be a bar free to rotate about the point *O* (Fig. 3). At the other end, *A*, suspend a weight *P* and from a string which passes over a pulley suspend a weight *Q*. Leonardo concludes that equilibrium will exist if $Pp = Qq$. This is nothing more than the principle of statical moment in the form in which we now use it. We do not know what process of reasoning led Leonardo to the discovery of this principle.

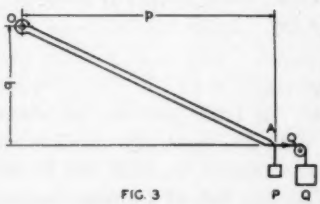


FIG. 3

Knowing now the law of the lever and the principle of statical moments, it is an easy matter to derive the law of the wheel and axis. That is (Fig. 4), equilibrium will exist if $Pp = Qq$.

Between Archimedes and Leonardo seventeen centuries elapsed, during which time little progress was made in the science of mechanics. Let us pause for a moment and consider what transpired between Archimedes, say 200 B.C., and the time of Leonardo, say 1500 A.D. We know that at the beginning of the Christian era, Rome's power was at its height. Now the Romans were not interested in science. In fact, they looked upon science as something beneath their dignity. It is said that not a single contribution to science of any consequence was made by a Roman. The development of science was left principally to the Greeks and the center of Greek thought in Archimedes' time was Alexandria in northern Egypt. But these Greek philosophers after Archimedes were interested more in astronomy and mathematics than in mechanics. Any one studying history knows that Rome at the beginning of the Christian era was very corrupt and that she was undermining her own strength; so much so that several centuries later she was not able to hold her own against the barbarians who came from the north in swarms and completely overran Italy. With the fall of Rome the Dark Ages set in and such Greek manuscripts as were left, being in Greek, could not be read. About the eleventh century signs of re-awakening appeared. This re-awakening was stimulated in part by the Crusades and in part by the entrance of Arabian culture from Spain. In 1453, however, an event occurred that had a profound influence upon the intellectual development of western Europe. That is, in 1453, the Turks conquered Constantinople. With the fall of Constantinople, an immigration from Greece into Italy began. These men took with them such Greek manuscripts as were then in existence, among which were those of Aristotle and Archimedes. The appearance of these Greeks and Greek manuscripts gave a decided stimulus to the study of Greek. Leonardo da Vinci, who was born in 1452, the year before the fall of Constanti-

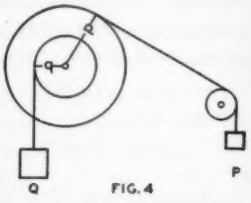


FIG. 4

nople, had access to these Greek manuscripts. On the reserve shelf you will find a book entitled *The Mechanical Investigations of Leonardo da Vinci.* From this it appears that Leonardo was on the verge of making a number of important discoveries, but, with the exception of the principle of moments, failed in the end.

It should be added here that by the end of the fifteenth century printing was established. Books began to appear and the Greek manuscripts in time became available to everybody.

Stevinus (1548–1620)

Stevinus discovered the law of the inclined plane by a very ingenious method. Let *ABC* be a triangular block with the

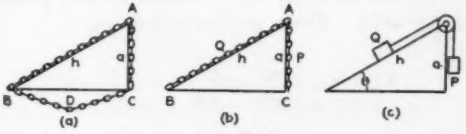


FIG. 5

face *BC* horizontal. On this block imagine an endless chain hung as shown. This chain will either remain at rest or it will begin to move. It is not reasonable to assume that it will move. Hence we must assume it will remain at rest. Now the symmetrical part *BDC* may be removed without disturbing the equilibrium (Fig. 5*b*). Hence the part *AB* of the chain will balance the part *AC;* that is, the weight of the part *AB* of the chain is to the weight of the part *AC* as *h* is to *a*. Or in general * (Fig. 5*c*).

$$\frac{P}{Q} = \frac{a}{h} = \text{Sin } \theta;$$

$$\therefore \quad P = Q \text{ Sin } \theta.$$

* It should always be remembered that all results will be put in modern form.

Stevinus seems to have been the first to employ the law of the parallelogram of forces. Given an inclined plane (Fig. 6*a*), assume that the weight Q is held in equilibrium by the weight P. Imagine a string attached to the weight Q. Pass this string over the pulley D, the pulley being so placed that the string is normal to the plane (Fig. 6*b*). From the other end of the string suspend a weight N equal in magnitude to the normal pressure between Q and the plane. Then as Stevinus correctly perceives there will be no pressure between Q and the plane. Moreover, equilibrium will not be disturbed. Draw the vertical line ab to represent Q and complete the parallelogram $acbd$. From similar triangles,

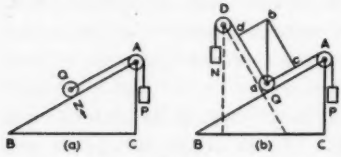


FIG. 6

$$\frac{ac}{ab} = \frac{AC}{AB}.$$

The law of the inclined plane, however, gives

$$\frac{AC}{AB} = \frac{P}{Q};$$

$$\therefore \frac{ac}{ab} = \frac{P}{Q}.$$

Hence ac represents P on the same scale that ab represents Q. Considering now the dotted inclined plane, P and N are interchanged, and in like manner it will be seen that ad represents N. Evidently the construction of the parallelogram $acbd$ is nothing less than the construction of the parallelogram of forces for the particular case where the strings ac and ad are at right angles to each other.

Later on Stevinus applied the parallelogram of forces to a more general case. Let OA, OB, and OC (Fig. 7) be three strings and let a weight P be attached to OC. If now OD is drawn vertically to represent P and the parallelogram $OEDF$

is constructed, OE and OF represent the tensions in the strings OA and OB, respectively. Stevinus used the parallelogram of forces in the solution of a number of problems. He did not, however, formulate the law; he simply used it. It was left to Varignon and Newton to generalize and formulate the law.

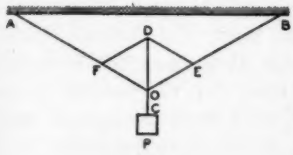


FIG. 7

To Stevinus we are also indebted for the conception of the principle of virtual work. In his investigation on the pulley and combination of pulleys (Fig. 8), he observed that if P and Q are in equilibrium, and if we suppose P to be lowered a distance s, and Q to be raised a distance h, then

$$Ps = Qh.$$

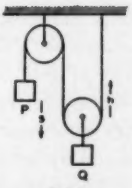


FIG. 8

Galileo later made use of this principle; in fact, he made virtual work the decisive factor in equilibrium. Consider for instance an inclined plane. Let P and Q be two weights (Fig. 9). If P is assumed to be moved down a distance s, Q will move up the incline a distance s, but will be raised vertically only the distance h. Galileo perceives that equilibrium will exist if, and only if, $Ps = Qh$; that is, if the work done by P = the work done in lifting Q.

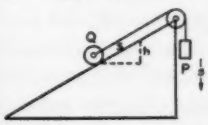


FIG. 9

The law of the parallelogram of forces and the principle of virtual work were subjects of considerable interest to subsequent investigators. A number of attempts were made to generalize and to prove these theorems geometrically. It is now generally admitted that the parallelogram law and the principle of virtual work cannot be proved without making some assumption the truth of which rests on experience.

Galileo (1564–1642)

We now come to Galileo. It should be kept in mind that by the time of Galileo, the law of the lever, and the law of the inclined plane were known and that these laws had been applied to a number of simple machines; that the parallelogram law and the principle of virtual work were recognized and that Archimedes had laid the foundation of hydrostatics.

Galileo entered the University of Pisa in 1581 to prepare himself for the profession of medicine. He became interested, however, in Euclid's geometry and the writings of Archimedes, and wrote an essay on the hydrostatic balance, indicating the method Archimedes must have used for detecting the fraudulent composition of Hiero's crown. The story of Hiero's crown is familiar to most of us. The King had given a quantity of gold to a goldsmith for the purpose of making a crown. When the crown was finished the King suspected that some of the gold was kept by the goldsmith and that its weight was made up by a baser metal. He sent the crown to Archimedes to find out whether the crown was solid gold or not. One day as Archimedes was taking a bath, which happened to be full, he noticed that some of the water overflowed. This set him to thinking and he perceived that the volume of water that flowed out must be equal to the volume of the body immersed and concluded that if the crown were suspended in a vessel of water quite full, the volume of the water that flowed out must be equal to the volume of the crown. Knowing then the volume of the crown, he could determine what the crown ought to weigh if made of pure gold. Archimedes then made experiments on the weights of a body in air and in water and made the discovery known as the principle of Archimedes, namely, "Every body immersed in liquid loses of its own weight a portion equal to the weight of the liquid it displaces." The story of Hiero's crown is of interest to us now since Galileo's first essay seems to have been inspired by this story.

This essay of Galileo's attracted the attention of a distinguished mathematician of this time who suggested to Galileo the problem of the determination of the center of gravity of

solid bodies. Galileo's treatment of this subject was so satisfactory that it led to his appointment as Professor of Mathematics in the University of Pisa. He was then twenty-six years of age.

Galileo's remarkable career now began. His investigations covered a wide range of subjects. His renown is due, however, chiefly to two things: his discoveries in mechanics and his defense of the Copernican system.

It does not seem possible to appreciate the importance of Galileo's work, unless we understand the difficulties Galileo had to overcome. Galileo had many obstacles in his way, but the greatest of all was Aristotle, who ruled supremely. By the time of Galileo, a man's standing in matters of learning depended upon his knowledge of Aristotle. In some way, the doctrines of Aristotle seem to have been incorporated into their religious doctrines, so much so that to most men of Galileo's time to question the authority of Aristotle seemed almost as unpardonable as to question the authority of the Bible. A dispute on any subject was considered as settled if a quotation from Aristotle could be given pertaining to that subject. To Galileo, however, a quotation from Aristotle was not sufficient. Even as a student, he developed a degree of intellectual freedom that became objectionable to his professors, and later as soon as he was settled in his position as Professor of Mathematics at the University of Pisa, he began to test Aristotle's physical doctrines. This was a new idea. Professor Millikan calls this the "birth of a new idea." There had been philosophers before the time of Galileo who dared question some of the doctrines of Aristotle, but there had been none who dared to go so far as to actually subject the venerable Aristotle to experimental tests.

According to Aristotle, a heavy body will fall to the ground through a given distance in less time than a light body. For centuries this was believed to be a fact. Galileo, however, performed some experiments and found it was not true. But in spite of ocular demonstrations he could not convince his colleagues that a heavy body and a light body will fall through

the same distance in the same time, any slight difference in time being accounted for by the resistance of the air. The Aristotelians argued that this cannot be true and they cited page after page of Aristotle to prove their point. They ridiculed the idea that Aristotle might be wrong. Galileo's own comment is significant: "They fancied science was to be studied like the Æneid or the Odyssey and that the true reading of nature was to be discovered by the collation of texts." To prove his point, Galileo invited his colleagues to witness for themselves the result of allowing two unequal weights to fall from the leaning tower of Pisa. Some refused to attend. Others did attend but they all refused to believe that Aristotle might be wrong. Galileo was even accused of possessing some occult power by virtue of which he was able to interfere with the natural laws of falling bodies. In answer to some of the objections raised against the experiment, Galileo in his *Dialogue on Motion* makes one of the interlocutors say: "Aristotle says that an iron ball weighing a hundred pounds will fall from a height of a hundred yards while one weighing one pound falls but one yard. I say they will reach the ground together. They find the bigger to anticipate the less by two inches and under these two inches they seek to hide Aristotle's ninety-nine yards."

Galileo now found himself in a very unpleasant position. He had not succeeded in proving that Aristotle was wrong, but he did succeed in creating an ill-feeling and opposition to himself. Galileo continued his criticisms and before long he found himself so unpopular that he was publicly hissed at his lectures. The hatred and opposition to him became so strong that he felt it advisable to resign and to accept the Professorship of Mathematics at the University of Padua.

In his new position he continued his researches in the various branches of science. Here he invented the air thermometer and the sector, and later constructed his first telescope which aroused great interest. He became convinced of the truth of the Copernican system, but out of compliance with popular prejudice he continued to teach the Ptolemaic sys-

tem. Due to the charm of his demonstrations, his lectures became so popular that a place capable of holding more than a thousand persons was none too large for his audience. He stayed eighteen years at Padua and then went to Florence, where he continued his study and investigation (Sept., 1610).

In 1609, while still at Padua, he constructed his first telescope and early in 1610 began his astronomical investigations with his telescope. The discoveries he made again aroused the antagonisms of the Aristotelians. At Florence he became bolder and began to defend the Copernican system openly. This brought him in conflict with the church.

Galileo's investigations in the field of astronomy resulted in discoveries that in themselves were not of very great value. His service to astronomy lies chiefly in the fact that he exposed so many of the fallacies of his time. To illustrate, it was universally believed that the moon must be perfect and that therefore it was round and smooth. When then Galileo turned his telescope to the moon and found that the moon was mountainous, he exploded a shell in the very midst of the Aristotelians of his time. They would not, they could not believe that the moon was mountainous. That was contrary to all their teaching. To admit that the moon was mountainous was equivalent to admitting that the very foundation of their belief might be wrong. Galileo, however, persisted in showing them by actual observation through his telescope that the moon was mountainous. He turned his telescope toward the sun and alas! he found spots on the sun. It was bad enough to declare that the moon was mountainous, but to declare that there were spots on the sun simply added insult to injury. Sheiner, a monk, having verified Galileo's observation, reported to his Superior the existence of spots on the sun. In reply the Superior wrote:* "I have searched through Aristotle and can find nothing of the kind mentioned. Be assured, therefore, that it is a deception of your senses or of your glasses." Many other discoveries were made by Galileo, all proving that the prevailing beliefs of his time were wrong.

* See *Makers of Science*, by Hart, page 116.

He thus earned the undying hatred of the Aristotelians of his time and when later he defended the astronomical doctrines of Copernicus, their patience was at an end. Even the pulpit began to preach against him. "Bishops and priests warned their flocks, and multitudes of the faithful besought the inquisition to deal speedily and sharply with the heretic."* Taking advantage of Galileo's habit of looking at the skies through his telescope, Father Caccini in his sermon against Galileo took as his text, "Ye men of Galilee, why stand ye gazing up into heaven?" It is stated that this pun was echoed from one end of Italy to the other. Galileo, however, persisted in his defense of the Copernican system and this led to his persecutions.

It was due to Galileo's investigations in astronomy and his defense of the Copernican system that this system was so readily accepted soon after Galileo's time. The Aristotelians rapidly lost ground and great interest was aroused in astronomy and mechanics. In fact, if Galileo had not so ably defended the Copernican system, Newton's *Principia* would not have been written.

Let us now consider some of the main discoveries of Galileo in the field of mechanics. He seems to have been the first clearly to understand the advantages of machines. Quoting Galileo: "If I mistake not I see almost all mechanics deceiving themselves in the belief that, by the help of a machine, they can raise a greater weight than they are able to lift by the exertion of the same effort without it. Now, if we take any determinate weight, and any force, and any distance whatever, it is beyond doubt that we can move the weight to that distance by means of that force, because, even although the force may be exceedingly small, if we divide the weight into a number of fragments, each of which is not too much for our force, and carry these pieces one by one, at length we shall have removed the whole weight; nor can we reasonably say at the end of our work that this great weight has been removed

* See *A History of the Warfare of Science with Theology*, by Andrew D. White, Vol. I, page 130.

and carried away by a force less than itself, unless we add that the force has passed several times over the space through which the whole weight has gone but once. . . . But the force will have to travel over that very same space as many times repeated as the weight surpasses its power, so that at the end of our work we shall find that we have derived no other benefit from our machine than that we have carried away the same weight altogether which, if divided into pieces, we could have carried without the machine, by the same force, through the same space, in the same time."

Expressed in another way, Galileo was the first to see that "you cannot get more work out of a machine than you put into it." In fact, Galileo makes virtual work the decisive factor in equilibrium. Expressed in the language of to-day, "if a system of forces is in equilibrium, then the total virtual work is zero." By virtual work is meant the work that would be done if the system is assumed as undergoing a displacement for which the system remains in equilibrium. This displacement may or may not actually take place. It must however be a possible one, one consistent with the constraints.

Galileo was the first successfully to investigate the laws of motion. He is the founder of the science of dynamics. The physical doctrines of Aristotle are so absurd that they have no scientific value except as an illustration showing that in the field of the physical sciences the laboratory is indispensable.

To ascertain the laws of freely falling bodies, Galileo proceeded as follows: He first made the assumption that the velocity will be proportional to the distance traversed: that is the velocity will be doubled when the distance is doubled, etc. He soon found that this assumption led to an absurdity and therefore was not tenable. He then discarded this assumption and made a second assumption according to which the velocity was proportional to the time of descent. That is,

$$v = at.$$

He found no contradiction in this assumption. He then perceived that if it is true that the velocity is proportional to the

time of descent, the distance traversed in a given time should equal the average velocity times the time, or

$$s = \frac{v}{2}t = \frac{at}{2} \times t = \frac{at^2}{2}.$$

That is, the distance traversed should be proportional to the square of the time of descent. He argues that if this is true for a freely falling body, it ought to be true for a ball rolling down an inclined plane. He then proceeds to investigate the motion of a ball rolling down an inclined plane to see if his theory is in accord with the results of experiments. To quote Galileo himself:* "In a plank of wood about eighteen feet long, nine inches wide and three inches thick, we made upon the narrow side or edge a groove of little more than an inch wide. We cut it very straight, and to make it very smooth we glued upon it a piece of vellum, polished and smoothed as exactly as possible: and in that we let fall a very hard, round, and smooth brass ball, raising one of the ends of the plank a yard or two at pleasure above the horizontal plane. We observed, in the manner that I shall tell you presently, the time which it spent in running down, and repeated the same observation again and again to assure ourselves of the time, in which we never found any difference; no, not so much as the tenth part of one beat of the pulse. Having made and settled this experiment, we let the same ball descend through a fourth part only of the length of the groove, and found the measured time to be exactly half the former. Continuing our experiments with other portions of the length, comparing the fall through the whole with the fall through half, two-thirds, three-fourths—in short, with the fall through any part—we found by many hundred experiments that the spaces passed over were as the squares of the times, and that this was the case in all inclinations of the plank."

In the time of Galileo there were no clocks or watches. Note how he overcame this difficulty. Quoting again: "As to the estimation of the time, we hung up a great bucket full of

* See Galileo's *Two New Sciences*, page 178.

water, which through a very small hole pierced in the bottom, squirted out a fine thread of water, which we caught in a small glass during the whole time of the different descents; then weighing from time to time in an exact pair of scales the quantity of water caught in this way, the differences and proportions in their weights gave the differences and proportions of the times; and this with such exactness that, as I said before, although the experiments were repeated again and again, they never differed in any degree worth noticing."

Galileo satisfies himself that his assumptions are correct and that the laws of falling bodies are:

$$v = at,$$
$$s = \tfrac{1}{2}at^2,$$
$$s = \frac{v^2}{2a},$$

the third law being obtained from the first two by eliminating t, the time.

If in the equation $v = at$, we put $t = 1, 2, 3, 4$, etc., we get $v = a, 2a, 3a, 4a$, etc. That is, $a =$ increase in velocity per unit time or the acceleration of the body. It should be remarked that Galileo had to create the notion of acceleration. Moreover, he had to create the notion of instantaneous velocity. Up to his time, velocity was thought of as a distance divided by time. This is correct if the velocity is constant. He was dealing, however, with variable motion and the concept of velocity held at his time had to be enlarged.

Galileo makes the assumption that if a body is thrown up with the same velocity it came down, it will reach its original height. If, for instance, a body is allowed to fall from a given height and if at any instant in its descent the velocity of the body were suddenly reversed in direction, the upward motion of the body would be a reflex of its downward motion. Assuming this true for a freely falling body, it ought to be true for a ball rolling down an inclined plane; that is, if a ball is projected up the plane with the same velocity it came

down it ought to roll up the plane to its original height. Galileo concludes that "If a body falls (slides) freely along smooth planes inclined at any angle whatsoever, but of the same height, the speeds with which it reaches the bottom are the same." That is, if a ball is allowed to slide down the inclined plane AB it will have the same velocity at B that it would have if allowed to fall freely through the same vertical height AC (Fig. 10). The proof of this theorem gave Galileo a great deal of trouble. One of his pupils expressing his dissatisfaction concerning the reasons given for this theorem, Galileo after a sleepless night finally discovered the proof he had sought for. This proof is given in his *Two New Sciences*.* The reasoning in this proof is not easily followed. In Galileo's time the accepted method of proving a theorem was almost entirely geometrical. The algebraic method is of more recent date. On account of the importance of this theorem, let us analyze Galileo's proof and put it in modern form.

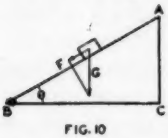


FIG. 10

Galileo asserts that the accelerating force along the inclined plane AB (Fig. 10) is to the accelerating force in a free vertical fall AC as the height AC is to the length AB of the inclined plane. Or, put in modern form, if G = weight of body and F = accelerating force acting down the plane AB, then

$$\frac{F}{G} = \frac{AC}{AB} = \sin\theta, \qquad \text{or} \qquad F = G\sin\theta.$$

Galileo assumes that the distance a body passes over *in a given time* is directly proportional to the accelerating force. Let us see what this implies. Now $s = \frac{1}{2}at^2$, or $a = 2s/t^2$. Hence, for a given time t, a is proportional to s. If it is assumed that for a given time s is proportional to F, it follows that a is proportional to F. That is, the acceleration produced in a given body is proportional to the accelerating force. Note that this is Newton's second law of motion. In fact, it is now agreed that we are indebted to Galileo for the second

* See translation by Crew and DeSalvio, page 184.

law of motion. He did not formulate this law, but the solution of his problems involves the recognition of this law. It was left to Newton clearly to formulate it.

It seems to me that Galileo's proof of the theorem concerning the equality of the velocities acquired by a body sliding down different smooth inclined planes may be taken as equivalent to the following: Let a = acceleration of a body down the inclined plane AB (Fig. 10) and g = acceleration of this body when falling freely. Then,

$$\frac{a}{g} = \frac{F}{G} = \sin\theta, \qquad \text{or} \qquad a = g \sin\theta.$$

If v_C = velocity at C when falling freely through AC, and
v_B = velocity at B when sliding down AB, then

$$AC = \frac{v_C^2}{2g},$$

or

$$v_C^2 = 2g\ AC. \tag{1}$$

In like manner, if a = acceleration down $AB = g \sin\theta$,

$$AB = \frac{v_B^2}{2a} = \frac{v_B^2}{2g \sin\theta},$$

or

$$v_B^2 = 2g \cdot AB \sin\theta = 2g\ AC. \tag{2}$$

Comparing equations (1) and (2), it is seen that

$$v_C = v_B.$$

That is, the velocity of the body at B when sliding down the smooth plane AB is the same as it would be if allowed to fall freely through the same vertical height AC.

As a result of this theorem, Galileo concludes after several pages of discussion * "that a body which descends along any inclined plane and continues its motion along a plane inclined upwards will, on account of the momentum acquired, ascend to an equal height above the horizontal." That is (Fig. 12) if

* See *Two New Sciences*, page 216, etc.

a ball rolls down AC and up CB it will reach a point B that is on the same level with the point A from which the ball started rolling.

It was characteristic of Galileo to want to subject his conclusions to experimental tests. To test his conclusion that the velocity of a ball rolling down an inclined plane is the same for all planes of the same height, he performs the following experiment:

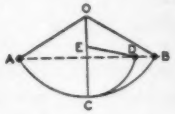


FIG. 11

He takes a simple pendulum OC and pulls the weight to one side to the point A (Fig. 11). Letting go, he finds that the weight swings to the other side and reaches a point B practically on the same level as A. He now drives a nail in the stand to the side of the thread as it hangs vertically. In the figure, E is the nail. He then pulls the ball back to the point A and letting go finds that the ball reaches very nearly the point D. That is, the weight goes down on the arc AC and up on the arc CD. Reversing the process, the weight goes down DC and up CA. There is a slight discrepancy. This discrepancy he attributed to the resistance of the air. He tests this by trying the experiment with a cork ball and finds that the discrepany is much greater when a cork ball is used than when a heavy metal ball is used.

Having proved to his own satisfaction that the velocity of a ball rolling down an inclined plane is the same as that of a body falling freely through the same height, he now proceeds to use this theorem in deriving other theorems concerning the motion of a body down inclined planes.

Galileo's theorem concerning the equality of the velocities acquired by a body sliding down different smooth inclined planes of the same height plays a very important rôle in the history of mechanics. For that reason, it was dwelt upon at some length. Later in 1673 Huygens, being dissatisfied with Galileo's proof, gave a proof that seems very clear and ingenious. On account of the importance of this theorem, Huygens' proof will be given.

Assume two planes as shown (Fig. 12). Let A and B be

two points on the same level. If a ball is started rolling up CA with the same velocity it came down AC, it ought to reach its original height A. In like manner, if the ball is started up CB with the same velocity it came down BC, it ought to reach its original level B. Now assume the ball to roll down AC and up CB. The velocity of the ball at C as it rolls down AC cannot be greater than the velocity it would have had if it had rolled down BC, for if it were, the ball would roll up CB beyond the point B. This is not admissible, for then a body could raise itself, which is contrary to experience. Experience shows that gravity always tends to lower the center of gravity of a body and that under no circumstances can a body ascend to a higher position than that from which it fell. In like manner, the velocity at C when rolling down AC cannot be less than the velocity the ball would have when rolling down BC. For if it were, we need only to reverse the operation and let the ball roll down BC and up CA and the ball would roll beyond the point A. This again is not admissible. Hence it must be concluded that the velocity of the ball at C is the same whether it rolls down AC or BC. If the plane AC is made steeper and steeper until it is vertical, we have the limiting case for a freely falling body. Hence it may be concluded that the velocity of a ball rolling down any inclined plane is equal to that of a body falling freely through the same vertical height.

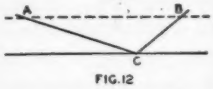


FIG. 12

We are indebted to Galileo for the law of inertia. It may be of interest to know how he was led to this law. It was seen that if a body is allowed to roll down the inclined plane AB and up BC, it will roll up BC to the same vertical height it descended when rolling down AB (Fig. 13). This will be so for all planes BC, BD, BE, etc. In the limit then it should be so also for the horizontal plane BF. Now the retardation up any plane, BE for instance, is

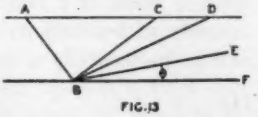


FIG. 13

$$a = g \sin \theta$$

where g = acceleration of freely falling bodies. In the limit then as θ becomes zero, the retardation becomes zero. Hence, if a ball is allowed to roll down AB on to a horizontol plane BF, it will roll on BF with undiminished velocity. Or in general * a ball rolling on a horizontal surface will continue in motion with uniform velocity in a straight line, provided all accidental and external impediments are removed. This, in essence, is the first law of motion, the law of inertia.

That Galileo recognizes the law of inertia as a general principle is quite evident. For instance, it was universally believed by the Aristotelians of his time that as soon as the impulse causing motion ceases, a body would fall vertically to the ground if it were not for the resistance of the air. They believed that the resistance of the air helped the body along. If then a body is thrown horizontally it would, in their opinion, begin to fall vertically as soon as it leaves the hand. The fact that it does not do so, they attribute to the resistance of the air. Galileo contended that this was all wrong. He contended that the horizontal motion of the body and the vertical motion of the body are entirely independent of each other, and that the resistance of the air retards the motion instead of helping it along. He contended that the body would move horizontally in a straight line with constant velocity if gravity were removed and that its vertical motion is exactly the same as if the body were allowed to fall freely with no horizontal motion, and concluded that the actual motion of the body is the composition of the two motions. Put in modern form, if a body is projected horizontally with a velocity v_0, in the time t it will go horizontally a distance

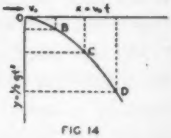


FIG. 14

$$x = v_0 t. \tag{1}$$

In the same time, it will fall vertically a distance

$$y = \tfrac{1}{2} g t^2. \tag{2}$$

Combining the two motions, the body would be at C at the end

* See *Two New Sciences*, page 215.

of say the second unit of time. The body therefore will move in a curve *OBCD*. Eliminating t between Eqs. (1) and (2)

$$\frac{x^2}{y} = \frac{2v_0^2}{g} = \text{a constant}$$

which, as Galileo recognized, is a property of the parabola. To Galileo, then, we are also indebted for the principle of the composition and resolution of motions; that is, for the parallelogram law as applied to motions.

It may be of interest here to give another illustration showing that Galileo understood the law of inertia. The Aristotelians held that the earth did not rotate. They argued that if the earth rotated, a body thrown up vertically would not keep pace with the surface of the earth for the reason that while the body was up in the air the surface of the earth moved on and hence it would not fall back to its original position on the earth. Since a body if thrown up vertically will fall back to its original position, it must follow, according to the Aristotelians, that the earth does not rotate. Galileo contended that this was all wrong. All bodies on the earth's surface, including the air, have the same velocity as the earth's surface. Hence if a body is thrown up, its inertia will carry it along so that it keeps pace with the earth's surface. It should be remarked here that Galileo did not use the term *inertia*. The terminology in mechanics is of more recent date.

Before the time of Galileo the only force that was recognized was pressure. The falling of heavy bodies was explained by assuming that every body seeks its own place and that the place of a heavy body was below. This doctrine of Aristotle involves no conception of a force as causing bodies to fall. Galileo, however, perceived that force causes acceleration. Hence where there is acceleration there is a force acting. This is the modern conception of force. It is not to be inferred that Galileo actually defined force. From his writings, however, it is clear that he had a right conception of force. In fact, it is now generally agreed that we are indebted to Galileo for the second law of motion.

Galileo was the first to notice that the oscillations of a

pendulum were isochronous, and a number of the properties of the pendulum were discovered by him. If we remember that the pendulum was one of the favored subjects of investigation of his successors leading to the discovery of some of the most important principles of mechanics, we see that Galileo's investigations pertaining to the pendulum, although of minor importance in themselves, are very important, as we shall see later on when we consider the effect these investigations had upon the development of mechanics.

It was recognized before the time of Galileo that a moving body can exert a force due to its velocity. That is, a moving body possesses a *living force* as it was later called. Since then the living force of a body depends upon its velocity, how can a body at rest resist the slightest change of motion and how can it exert any pressure at all since its velocity is zero? Evidently something more than velocity is involved and it began to be recognized that the weight of the body had something to do with the living force, but the relation between living force of a body, its weight and its velocity was not understood. Now Galileo called the living force of a body the *momentum* of this body and as a result of his study and experiments with moving bodies he concluded that the momentum of a body depends upon its weight and is directly proportional to its velocity, that is, momentum = weight times velocity. (No distinction between mass and weight was made until some time after Galileo.)

Now Galileo's conception of momentum as the living force of a moving body is partly right and partly wrong as the following analysis will show. Limiting ourselves to the case of uniformly accelerated motion of a body starting from rest, we have $v = at$. Multiply through by M, the mass, we have since $Ma = F =$ accelerating force,

$$Mv = Ft,$$

from which it is seen that the momentum Mv is a measure of the force, F, a body can exert (the living force) provided we add *in a given time* t. That is, the momentum of a body may be thought of as a measure of the force a moving body

can exert or of the resistance this body can overcome *in a given time* before it is brought to rest. Galileo, therefore, did not fully understand the meaning of momentum nor was it fully understood for a long time afterwards. We shall see that Galileo's conception of momentum led to a dispute among physicists that lasted for more than half a century.

Let us now summarize Galileo's achievements in the field of dynamics. He gave us the concepts of acceleration and instantaneous velocity. To him we are indebted for the modern conception of force. He discovered the laws of falling bodies. He recognized the first and second law of motion. He generalized the parallelogram law so as to apply to accelerations and motions. He discovered a number of the properties of the pendulum. He gave us the concept of momentum. Moreover, Galileo introduced a *new idea*. Previous to Galileo, with few exceptions, if an idea seemed reasonable, it must be so. Galileo, however, proceeded differently. If an idea seems reasonable, let us test it experimentally and see if it is so. Beginning with Galileo, theory and the laboratory began to go hand in hand. Remembering now that practically nothing was known of the science of dynamics before his time and that his life was one continuous fight against the notions of his time, Galileo's achievements must be considered as remarkable.

Just a few words concerning Kepler (1571–1630). Kepler and Galileo were contemporaries and were in the habit of corresponding. Kepler was a remarkable man. He discovered the three laws of planetary motion which had a profound influence upon astronomy and indirectly upon mechanics. Now Kepler's laws of planetary motion were in direct opposition to the Aristotelian notions of his time. To show how hard it was for a man even of Kepler's type to free himself completely from the notions of his time and particularly from the Aristotelian notions, witness his argument against the prevailing notion that the planets were carried in their orbits by angels. He argues that it can not be angels that carry the planets in their orbits, for in "that case the orbits would be perfectly circular; but the elliptic form which we find in them rather smacks of the lever and material necessity."

Mysticism

It is not difficult to see why the Aristotelians should resent Galileo's statement that all bodies fall through the same distance in the same time (neglecting the resistance of the air) since Aristotle explicitly states that this is not the case. But Aristotle does not mention spots on the sun, or mountains on the moon. Why then should the Aristotelians fly into such a fury when Galileo announced that he discovered spots on the sun and mountains on the moon? This leads us to the subject of mysticism.* Mysticism took many forms and often developed into magic. It is beyond the scope of this lecture to discuss mysticism in detail. Suffice it to say that this strange philosophy affected the growth of science very much and for that reason it will not be out of place to say a few words concerning certain phases of it.

For our present purposes, mysticism will designate any theory or doctrine or practice which assumes that the events of this world are dependent upon arbitrary supernatural agencies instead of being the natural consequences according to the natural law of cause and effect, or that the things of this world have special virtues entirely independent of their physical or chemical relations to each other.

All ancient civilizations ascribed certain virtues to certain numbers and figures. This was particularly true of the Greeks. The number seven was thought sacred to Minerva, the number six was a perfect number and was sacred to Venus. The numbers, three, four, etc., all had their mystical interpretations. Some numbers were associated with the quality of goodness or beauty and others with fortune or misfortune. It is not surprising then to find that in the Middle Ages numbers were given mystical interpretations. Even today, this mystical interpretation of numbers still exists to some extent. Among the uneducated, it is not uncommon for people to avoid starting out on a long journey on the

* See "Mysticism," Encyclopedia Britannica; or *History of the Inductive Sciences*, by Whewell, page 211; or *Science of Mechanics*, by Mach, page 446.

thirteenth of the month. Who would dare to set Friday the thirteenth for his wedding day? All this is simply an echo of mediæval mysticism. In like manner, certain virtues were attributed to geometrical figures. For instance, the circle and the sphere were thought to be perfect figures.

This mystical interpretation of numbers and geometric figures once accepted, it is not a great step to give a peculiar religious interpretation to things. Thus, God is perfect and the creator of all things. It is therefore logical to assume that he created the sun, moon and stars perfect. Hence they must be smooth and spherical. In like manner, the orbits of the planets are perfect. Therefore, these orbits must be circular. To make any other assumption was even considered impious by many for it predicated imperfection of the creator who himself is perfect. On January 7, 1610, Galileo made his most sensational discovery, for he discovered that Jupiter had moons like the earth. This created amazement everywhere and consternation among the Aristotelians. On hearing of this discovery, the great Kepler according to his own story was seized by a fit of wonder at a report that seemed so absurd, and was thrown into great agitation.* He could not see that there could be any additions to the number of planets (the satellites of Jupiter were first spoken of as planets) since "Euclid's five regular solids do not allow more than six planets around the sun."† His whole argument has a flavor of mysticism. What have Euclid's five regular solids to do with the number of planets? To-day, there are eight primary planets and many small or secondary planets, the asteroids. All this illustrates how mysticism in one form or other affected the scientific investigation even of men such as the great Kepler. Kepler, however, soon accepted Galileo's discovery, but the Aristotelians did not. They gave all sorts of arguments against it. Witness the following argument which is based upon supposed mystical properties of the number seven.

"There are seven windows in the head, two nostrils, two

* See *Pioneers of Science*, by Oliver Lodge, page 106.

† Mercury, Venus, Earth, Mars, Jupiter, Saturn.

eyes, two ears, and a mouth; so in the heavens there are two favorable stars, two unpropitious, two luminaries, and Mercury alone undecided and indifferent. From which and many other similar phenomena of nature, such as the seven metals, etc., which it were tedious to enumerate, we gather that the number of planets is necessarily seven.*

"Moreover, the satellites are invisible to the naked eye, and therefore can have no influence on the earth, and therefore would be useless, and therefore do not exist.

"Besides, the Jews and other ancient nations as well as modern Europeans have adopted the division of the week into seven days, and have named them from the seven planets: now if we increase the number of the planets this whole system falls to the ground."

In the face of all this opposition, Galileo remained firm and often became sarcastic. For instance, when one of his opponents who had refused to look through the telescope at the moons of Jupiter died, Galileo remarked: "I hope that he saw them on his way to heaven."

We thus see how religion, mysticism and Aristotelianism were all interwoven. We also see one reason why Galileo's discoveries aroused such opposition.

Mysticism was not restricted to numbers and geometric figures. It was believed that man's life and character were determined by the configurations of the stars at the time of his birth. Thus astronomy become astrology. Even the great Kepler added to his meager resources by practicing the art of astrology.

We are very dependent upon the materials around us. Naturally, then, mysticism was also applied to the metals. These metals were given qualities entirely independent of their physical or chemical qualities. Gold was thought to be the most pure, most nearly perfect and most noble of all the metals, silver came next, etc. It was thought that there was a striving for perfection among the metals and that some mysterious agency must exist which will elevate a baser metal into a

* Moon, Mercury, Venus, Sun, Mars, Jupiter, Saturn.

higher and more noble metal. The search for this mysterious agency, the "Philosopher's Stone" or the "Philosopher's Tincture," transformed chemistry into alchemy. This mysterious agency was assumed to have wonderful magical qualities and was sought for as the "elixir of life." That such a conception of things affected the growth of science is self evident. Even the great Newton in the early part of his life was interested in alchemy but soon concluded that it was hopeless to find the Philosophers' Tincture.

That mysticism often should transform science into magic is a foregone conclusion. Even great men dabbled in the so-called "occult science." The great Napier, the inventor of logarithms and a great mathematician, was an ardent Protestant and a great theologian, but he believed he possessed mysterious and magical powers. When one thinks of the intellectual conditions in which men lived in those days, one is struck not by the fact that the number of scientists were few but rather by the fact that these few men were able to strike out into a field so radically different from all the superstitions and beliefs then prevailing.

GIVE YOURSELF A CHANCE

By P. G. Laurson

(Presented at the Cornell Session on July 21, 1927)

I have been asked to show how I conduct classes. Perhaps I can make it of some use to my listeners by using a very indirect method. Instead of trying to pretend that I am in class I am going to present some thoughts that seem to me to embody what is good (if there is anything good) in my methods.

The text of my sermon is "Give yourself a chance." It is for beginners in teaching only. Even some beginners have discovered all the ideas that I have to offer. I hope to discover more ideas of the same sort as I go along, for I haven't yet taught as many years as I spent in engineering work before I began teaching. We all, beginners or not, want to do

our best at teaching as we want to do our best in other things. What I mean by "give yourself a chance" is this: Develop your good qualities in teaching and suppress the less desirable qualities. Use every device that will help to make good teaching easy and ineffective teaching less easy. Try to cut down your handicaps. Form good habits as you go along, not bad ones. Don't allow yourself to get stale.

I often think that if we could get our students to attack their studies in the same intense, effective, enthusiastic way that they "heel the college paper" or work for the crew or track team, our troubles would be over. We never can do it.

What I want to emphasize now is that if we ourselves would tackle our jobs with the same intense, effective and enthusiastic spirit that we long to see in our students, our improvement would be rapid instead of slow, as it often is.

I am not presuming to give the rules for learning to play our game. One that applies to this as to anything else and covers them all, in a way, is this: "Use your head." Don't be so busy that you haven't time to look at yourself and your job with the idea of seeing what your job requires and what you lack. Students working to make the teams have the advantage of expert and frequently expensive coaching. We must often work out our own salvation. Our game isn't standardized as are athletic competitions. It isn't played the same way in two schools nor is it played the same way two years in succession. There aren't any professional coaches. The best you can hope for is advice from some one who has played longer than you have and presumably plays better. Ask for it and follow it if (and only if) you feel that it fits your case. But don't reject it just because you don't like it. Give yourself a chance.

I wasn't asked to give you advice to-day. I was asked to show you how I teach. Well, I can hardly do that in the few minutes left and without a class of students, dumb and keen, prepared and unprepared, willing and half willing, to work on.

So I want to tell you in a few words what I do, and speak of some of the things I find useful.

When I meet a class my success or failure is almost predetermined. If I am well prepared I can hardly fail completely. If I am poorly prepared I can hardly succeed. Other things affect the degree of my success but without adequate preparation there can't be any success at all. I began preparing for this class years ago when I first studied the subject, but it's the recent preparation that counts. It is too late now to do anything about the earlier preparation. To get down to brass tacks, preparation means studying the assignment. You need to study it twice as much as your students need to. Preparation means working the problems. It also includes a plan of campaign covering the exercise—a program for the hour. This will vary from time to time and from course to course. The problems in the text should be worked—some should be worked the day before even if you did work them all two years ago.

Only by planning your campaign will you be able to keep up with the schedule and still cover the ground. You haven't any time for lost motion. My preparation for to-day must also cover my assignment for to-morrow—text and problem both. I have found it positively dangerous to assign a problem before I have worked it, however innocent it looks. It is only by working it that I can judge its usefulness. This is especially true when I invent the data. Keep a record of the stumbling blocks. The boys will stumble over the same ones next year unless you can warn them in advance. Notes jotted in the margin of your text will make it a de luxe edition indeed. Play the game with your boys fairly. They have an exquisitely keen sense of justice—when it is justice to them.

With this vividly impressed upon us, our department is trying the scheme of issuing to each student at the beginning of the course a mimeographed sheet which we might call the "rules of the game"—but we don't call it that. We list in this what we expect the students to live up to. We tell him that neatness and logical orderly arrangement counts for something—that if he misses a quiz (which the regulations of our school requires us to announce a week in advance) he can only make it up if his absence was for a cause which the office

regards as a valid excuse. If we merely announce this at the first exercise with lots of other things, it doesn't stick. When the occasion arises the student tells us that he didn't hear us say that, or that he was absent that day. We then firmly say that that doesn't excuse him but he feels that he has a grievance against us—that we are handling him roughly. This feeling should be prevented if possible. On this sheet we tell the student that late work will not receive full credit—which he agrees is fair enough if he knows it in advance. We tell him that 8½ x 11 paper is to be used. Then if he doesn't live up to our requirements he can be penalized fairly.

It is fair to have a pretty good understanding about how you are going to determine term grades. We have the *right* to be arbitrary in this matter but an understanding makes for more cordial feeling.

Discipline. I am glad to say that our students are gentlemen. But they are also boys, with a boy's love for "getting somebody's goat"—yours as well as anyone's. Hit back and hit hard if the need arises, but don't lose your head. Don't get mad or "see red." If you do the joke is on you and the boy is the victor. If you can keep cool you are pretty sure to win. The bystanders will punish the offender.

Let me list some of the material aids to good teaching. Teaching is a business and requires equipment and system. A comfortable chair, a convenient desk, good light, a filing case of some sort for quizzes and papers, a box for problem cards, binders for loose sheets, all are indispensable and ought to be provided by the company you work for. It is a hard enough job with all the helps available. Give yourself a chance.

The department in which I work finds mimeograph and hectograph machines indispensable. We run off when needed:

1. Additional notes clearing up or enlarging upon the text.
2. Problems—especially class problems.
3. Quizzes.
4. Final examinations.
5. Announcements, schedules, etc. for use of members of the department.

The use of the duplicating machine for class problems and quizzes is worth some emphasis. Our practice is to state the three problems of our typical quizzes on a sheet with a space for their solution, on the same sheet. This avoids mistakes of copying, but most important, it saves time for the students. We can cover about twenty-five per cent to fifty per cent more in a quiz so presented than in one written on the blackboard. The time we spend in duplicating is paid back to us when we correct the papers.

For class work the hectographed sheets save even more time. Figures may be drawn to scale and rather good results may be expected by graphic methods done free hand in a few minutes. Part of the solution may be given, leaving only the really vital work for the student to do.

Our practice in regard to looking over quizzes is to distribute the questions. I look over question one, Billy looks over question two, etc. More uniformity of grading results. Each enters his grade for the questions not on the student's paper but on a quiz record sheet which has space for the complete record, question by question, of all the quizzes for the term.

Similarly the department keeps for each course a master list. We may have 180 men in mechanics in ten or twelve sections which are not alphabetically divided. A complete alphabetical list of all students in the course is made up with spaces for entering all quiz grades, a grade representing class work for the term, final examinations, and any other significant marks. From the marks on this sheet and personal knowledge of the student the term grade is made up and entered on it. These sheets are carefully filed, year after year, in a loose-leaf ledger binder, and constitute a complete chronological and alphabetical record of the work of the department.

About half of the time I give the class a seat problem at the beginning of the exercise, covering work which any student should have no trouble with if conscientious preparation has been made. This helps to prevent habitual dependence upon class explanation. The student realizes that his mark for the

day may depend on his preparation before class rather than on his cleverness in absorbing information during the class. I do not give help during class papers nor do I expect help to be given by fellow students.

I have always assigned homework problems, copiously. Now that I see that many do not use them I wonder if I am wrong. My idea is this: Granted that some will copy them, I still contend that those who really want to get something from the course will do them conscientiously. After all, I am interested in those who *want* to do their work. The average assignment can be read over by a good student in about half the allowed preparation time. He may then glance at a problem or two and call it a day. But if he has problems to hand in he *must* use the rest of his preparation allowance—and those who do work their own problems are using this time in the very best way instead of not using it at all. I do not count the home work heavily in making up term marks but the student who hasn't done much of it gets no sympathy if his marks are low.

Ten Commandments or rules to govern teaching:

1. Do not come to class without adequate (and recent) preparation.
2. Do not assign work without having worked it yourself.
3. Do not assign too much work, but insist upon thorough work.
4. Do not make quizzes and class problems too long and hard.
5. Don't worry too much about whether problems are practical.
6. Don't get behind the schedule.
7. Hold yourself up to the standard you set for the students; promptness, neatness, accuracy, and thoroughness. Water doesn't rise higher than its source.
8. Before you answer a question be sure you have understood it. Students usually state questions badly and many times questions remain unanswered because they were never understood. Insist on clear questions as well as clear answers.

9. Be a good fellow but don't be soft. Boys like and respect a man who holds them up to high standards. Don't let your course get a reputation as an easy one.
10. Cultivate interests beyond and outside of the immediate requirements of your class work. A good teacher is something more than a teacher. The college is not a cloister to take refuge in from the opportunities and responsibilities of life. The teacher and business man do not materially differ in their needs for recreation and activity outside of their offices.

GIVE YOURSELF A CHANCE!

SUMMARY OF RESULTS OF A STUDY OF METHODS OF TEACHING MECHANICS

BY CURTIS MERRIMAN

(Presented at the Wisconsin Session on July 13, 1927)

REPLIES FROM TEACHERS OF MECHANICS

The following tabulation covers the replies received from sixty-nine teachers of mechanics in twenty-nine institutions.

1. *Teaching ranks of and degrees held by teachers replying:*

Teaching Rank.	Number.	Degree.	Number.
Professor	21	Third Degree	2
Associate Professor	9	Second Degree	40
Assistant Professor	25	First Degree	17
Instructor	14	Unstated	10

2. *Years of teaching experience:*
   Range: 0.5 to 44. Median: 8.5. Middle 50%: 4 to 18.
3. *Number of students per section:*
   Range: 8 to 60. Median: 20. Mode: 20 ±. Middle 50%: 16 to 20.
4. *Basis of determining membership of sections:*
   Ability as indicated by previous grades: 9.
   Without reference to ability: 60.
5. *Length of recitation period:*

50 to 55 minutes in majority of cases; 3 hour combined study and recitation periods reported by a few.

6. *Requirements as to keeping problem and exercise note-books by students:*
   Requirement made: 21. No requirement made: 46.
   No requirement—but recommendation, reported by many.
7. *Authorship of final examination:*
   Teacher replying: 36. Committee: 27.
   Head of department: 6. Assistant: 2.
8. *Basis of recognition of students' completion of course:*
   (Replies from 60 teachers, who marked items 1, 2, 3, etc. in order of importance)

	1	2	3	4	5	6	7	Total Replies
Ability to pass final examination	12	9	5	12	4	1	1	44
Ability to derive and demonstrate theory and formulas	16	3	7	4	3	1		34
General knowledge of theory and formulas	12	10	10	3	2			37
Ability to solve text problems and exercises	20	15	7	3	4			49
Ability to suggest more than one solution of problem	1	4	1	3	5	3		17
General average of grades in written and oral quizzes	27	11	8	2		2		50

9. *Procedure in beginning work on new topic:*
   Assignment of text and problems for preparation for next class { without explanation: 12. / with explanation: 42.
10. *Number of problems and pages assigned per lesson:*
    Problems: 3 to 5. Pages of text: 4 to 5.
11. *Quality of students' work:*
    Not passing: 10%. Poor: 20%. Average: 50%. Excellent: 15%. (Percentages approximate.)
12. *Causes of student failure:* (Marked 1, 2, 3, etc. in estimated order of importance)

	1	2	3	4	5	6	7	Total Replies
Lack of ability or capacity	20	13	10	7	8	1	1	60
Lack of application	25	14	10	8	1		1	59
Inadequate preparation	15	18	7	4	9	1		54
Lack of interest	10	10	12	11	8	2		53
Text too difficult			1	4	3	9		27
Extra-curricular activities	5	8	18	11	10	1	2	55
Content of course too theoretical				3	2	10	7	22

13. *Objectives of course in mechanics:*

For use in later work: 63. For mental training: 33. For cultural value: 1.

Replies from Students of Mechanics

The following tabulation covers replies from 688 students in courses of mechanics. Five institutions were represented, as follows: Minnesota: 165; Purdue: 272; Wisconsin: 170; Iowa: 47; Illinois: 34.

1. *Time spent in preparation of each day's assignment in mechanics:*

Number of Hours	Total Replies	Replies from * Purdue Students	Net Replies
0.5	111	94	17
1	199	117	82
1.5	125	25	100
2	181	15	166
2.5	13		13
3	30		30

2. *Interest in mechanics:*

Strong interest: 150. Average interest: 484. Little interest: 44. No interest: 5.

3. *Relative interest during study and class hours:*

* This separation of replies was made because Purdue students indicated uniformly less time spent in preparation than did the students of the other colleges.

Study hour more interesting: 101. Class hour more interesting: 428.

Little difference in interest: 132.

4. *Interest in mechanics as compared with that in other subjects:*

Mechanics most interesting subject: 89. Least interesting: 16.

Mechanics more interesting than laboratory and design courses: 241. Less interesting: 128.

Mechanics about the same as other subjects: 16.

5. *Mastery of mechanics as estimated by students themselves:*

Thorough: 28. Fair: 458. Incomplete: 187. Very slight: 16.

6. *Opinions of students as to ability of teachers of mechanics:*

Ability well above average: 238. Above average: 275. Average: 159.

Below average: 11.

7. *Instruction in mechanics as compared with that in other subjects:*

Better than in mathematics: 425. Poorer: 128.

Better than in English: 408. Poorer: 59.

Better than in science: 441. Poorer: 102.

8. *Criticisms of course in mechanics:*

Instructor's questions not clearly worded	40
Instructor talks too much	48
More class discussion needed	180
Students' questions not encouraged or satisfactorily answered	40
Instructor's voice monotonous	21
Too frequent resort to sarcasm by instructor	39
Time wasted on obvious or irrelevant points	55

9. *Number of students who had failed to pass a course in mechanics:*

Failures: 96. No failures: 549.

10. *Average grades in engineering:*

Good: 187. Average: 457. Poor: 36.

Relative proportions the same in all schools.

11. *Opinions of students as to more helpful way of presenting new problem to class:*
(Students were asked to check the method which they found more beneficial.)
Solution of problem by students at blackboard with incidental assistance from instructor: 153.
Solution of problem by instructor on the blackboard, with running discussion with class: 505.

12. *Opinions of students as to benefits derived through solution of previously assigned problem at blackboard by a student, with explanation to other members of the class:*

	Considerable	Very Little
Value of practice in public speaking to student at board	181	441
Value of student's explanation to other members of class	162	452

13. *Preferences of students concerning short reviews as against longer final review:*
Short reviews preferable: 433. Not preferable: 224.

14. *Preferences of students as to shorter and frequent quizzes, and as to longer and infrequent quizzes:*
Shorter quizzes preferable: 507. Longer quizzes preferable: 143.

LESSONS FROM A GREAT LIFE

By C. S. Slichter

(Presented at the Wisconsin Session on July 18, 1927)

This is the Bicentenary of Sir Isaac Newton, and throughout the world commemorations have been held worthy of his great name. Newton is one of the three national heroes of England. The only men we can bracket with him are Nelson and Wellington; Shakespeare, even, seems to be put in a slightly less heroic class by the Britisher. Newton's life is full of lessons of the highest interest to everybody, especially

to citizens of the university world. It is fitting that we pause long enough to honor a man who has done so much to honor learning and who holds such an outstanding position among the scholars of the ages.

Genius cannot be explained by heredity. Archimedes sprang from a family of kings, but that does not explain but only obscures his special genius. Newton sprang from a family of sturdy, honorable farmer folk who owned the manor of Woolsthorpe, worth only about the annual sum of thirty pounds. Therein you can find no explanation of his great genius, although it may help explain his simple tastes, and his straightforward and wholesome character. When Newton was knighted late in life he could trace back his ancestry for the College of Heralds no further than his grandparents, showing how simple had been the annals of his people.

There, in the manor of Woolsthorpe, early on Christmas morning in the year 1642, the future great philosopher was born. The infant thus brought into the world was of such diminutive size that, as his mother frequently expressed it, he could have been put into a quart mug, and so feeble that he was not expected to survive but a few hours. But notwithstanding the tonics and anise tea and other concoctions of those days that were abundantly administered to the frail infant, he grew in stature and in health into a fine and normal childhood. His father had died five or six months before Newton's birth and only two or three months after marriage, so Newton never had the advantage of his father's care. When Newton was but three years of age, his mother married the Rev. Barnabas Smith of Northwitham, a neighboring clergyman of good estate. She left young Newton at Woolsthorpe in charge of her mother, and her brother James and his wife.

Newton attended the day schools in Skillington and Stokes about a mile north of Woolsthorpe, where he acquired the three R's. It is not at all unlikely that the lack of parental care and discipline was, as a matter of fact, a fine thing for the boy Newton. Under the care of a sweet and loving grand-

mother and of an indulgent and kindly uncle, young Newton could muse and dream and make all sorts of machines and models and youthful inventions. His hammers, saws, and tools were his only playthings and his daydreams, his fancies and the images created in his own fertile mind were his only playfellows. When Newton reached twelve, he was sent to the public school at Grantham, six miles north of Woolsthorpe, then taught by a Mr. Stokes, an excellent teacher and a man of character. He boarded at the house of a Mr. Clark, an apothecary.

Newton seems to have been much more interested in his own musings and in constructing water clocks, windmills, kites and self-propelled carriages than in his studies in school. He was extremely inattentive and stood very low in the school. When he stood last in the next to lowest form, the boy next above him teased him about his standing and emphasized his lack of grade points by giving Newton a kick in the stomach. This was too much for Newton and as soon as school was dismissed Newton challenged his assailant to a fight and for this purpose they went into the churchyard. The schoolmaster's son came up during the fight and encouraged them both to continue the encounter. Although Newton was less robust than his antagonist, yet within him lay the spirit and the resolution and therefore he beat his opponent into submission until finally he would fight no more. The schoolmaster's son, who seemed to be a reservoir of grammar school traditions, told Isaac that he must treat the other as a coward by rubbing his nose against the church wall. The victor accordingly took his victim by the ears, dragged him over the tombstones to the church and thrust his nose against the wall. Thus ended the first victory of our hero and quite characteristic is it of those coming events of the years to follow, when this mild-tempered, timid and contemplative Newton was roused to battle in the many contests over claims of priority for his discoveries and inventions. His first antagonist, although vanquished in the churchyard, continued to stand above him in school. Finally this galled Newton, so he set out to win the moral as well as the physical vic-

tory. After a severe struggle during which he and his adversary were alternately successful, Newton not only won scholastically over his rival but rose to the highest place in the school.

I cannot find that this thoughtful and quite sober and silent lad was very different from scores of country boys who delight in the use of tools and spend their leisure in making things rather than playing with their fellows. There are probably many farm boys in Wisconsin who are now doing much the same thing. Newton and John Muir are but types. Not only with tools, but with pencil and pen the young Newton became quite expert, and drawings and poetry adorned his room—this last adventure may explain his dislike for poetry in later life.

During the seven years Newton spent at Grantham, he found it more to his liking to spend a few hours with the ladies of the household rather than with the boys of the school. There his only romance originated. One of the young girls was a Miss Storey, who was two or three years younger than Newton. She seems to have been a girl of unusual cleverness and personal attractiveness. Newton was really in love with her, but the smallness of her portion and the inadequacy of his income later when a fellow at College, prevented their marriage. Newton's affection for her continued through life and was not interrupted by her marriage to another. He paid her regular visits whenever he went to Woolsthorpe and he aided her generously when amidst the changes and chances of her life, there was need for friendship.

Newton at the age of seventeen or eighteen was entrusted with the management of the farm and his career was planned to be that of a farmer. But this big-eyed boy was too much given to study and to all sorts of experimentations to be of much use in the management of a farm. Instead of attending to his trading at the neighborhood market town, he would spend his time jumping with, and then against, a strong wind, to measure the force of resistance of the air, or in watching the millwrights erecting a Dutch windmill on the road to town.

His mother was soon convinced that her book-loving son, who had covered the roof with all sorts of contraptions and the walls of the house with sundials, was not destined to be a cultivator of the soil, so she wisely resolved to give him all the advantages which an education could bestow. He was therefore sent back to Grantham for another year and then in 1661, after taking counsel with her brother, the Reverend Ayscough, rector of a neighboring parish, it was arranged that Isaac should enter Trinity College, the Rector's own college at Cambridge. Newton left Grantham the head of the school, with the praises and the blessings of the aged master.

Cambridge became, therefore , "the birthplace of Newton's genius, her teachers fostered his earliest studies, her institutions sustained his mightiest efforts," her spirit of freedom and the lack of all mechanical control promoted still further the independence and resourcefulness his early life had cultivated, and within her precincts were all his discoveries made that were made. He created of Trinity College a temple wherein his spirit still broods and he quickened those college halls and those walls of stone with immortal life.

Little detail can be supplied concerning Newton's undergraduate years. He entered Cambridge as a subsizer, which means that he waited on table and paid nothing for board and little for lodging. He spent all the money he could get for books, and tools and prisms and such things. He seems to have set out immediately on a life of strenuous intellectual toil, adding always to his hours of work by subtracting from his hours of sleep. He soon read Saunderson's *Logic* and Kepler's *Optics* and books on astrology and alchemy. But his introduction to geometry was not auspicious. He bought an English Euclid with an index of propositions at the back. He looked these over, and deeming the contents quite obvious, he pronounced it "a trifling book," without ever having turned into the book itself. Thus it happened that he read Descartes' *Geometry* before he had mastered Euclid. He was appointed scholar at the end of April, 1664, and Dr. Barrow examined him in Euclid and formed but an indifferent opinion of his

knowledge. On account of this he was led to read Euclid with care and in consequence to change his mind about it as "a trifling book." He read Wallis's works and Oughtred's *Clavis*, making many comments and annotations and inventing his own method of infinite series, the beginning of his fluxions. His B.A. degree was won in January, 1665. From the summer of that year until October, 1667, the University was dismissed on account of the scourge of the Black Death. These months at home were among his most productive, showing that college halls are not absolutely essential for intellectual growth. He worked with books and all manner of things. He bought prisms, compasses, magnets, glass bubbles, *History of the Royal Society, Philosophical Intelligences*, drills, mandrels, hones, gravers, and hammers. It was then that he invented the method of fluxions, the first paper in his note book being dated May 20, 1665. He computed the area of the hyperbola to fifty-two places and on November 13, 1665, applied fluxions to the determination of tangents and of radii of curvature. He worked out the fluxions of surds in October, 1666 while still in Lincolnshire. It was during these months that the apple fell at Woolsthorpe and he began his speculations concerning gravity.

When college finally opened in October, 1667, he was elected Junior Fellow. In testing out his theory of gravity he laid aside his computation of the moon's motion, because, as usually stated, the then accepted radius of the earth was five hundred miles too short, and hence he could only account for seven-eighths of the moon's motions, or possibly (as Professor Cajori states), because he was held back by the difficulty in determining the law of mutual attraction of two spheres. But at this same time Newton was not idle in his workshop or "elaboratory" or "glass works" as he called it. He was grinding lenses, observing comets, playing with alchemy, and from 1667 to 1669 made his discoveries on the composition of white light and the properties of the spectrum. He dropped his "glass works" when he found that the different parts of white light could not be brought to a focus at a single point, and that the hope of powerful telescopes seemed to lie in build-

ing a reflecting instrument. Newton constructed a small one, saw four satellites of Jupiter and the horns of the crescent of Venus. Then in the ardor of youth he set himself to build another reflecting telescope. When its existence became known to the Royal Society, Newton was requested to send his instrument to that learned body, which he did towards the close of 1671. So great indeed was the interest which it excited that Mr. Newton was proposed for membership in the Royal Society by Bishop Ward, Savilian Professor of Astronomy at Oxford. The thanks for the telescope and notice of his election were conveyed to Newton in the same letter, and the letter was so cordial that Newton was led to write Secretary Oldenberg on January 18, 1672, as follows: "I am purposing them to be considered of and examined on account of a philosophical discovery which induced me to the making of the said telescope and which I doubt not but will prove much more grateful than the communication of that instrument, being the oddest if not the most considerable detection which hath hitherto been made in the operations of nature." This "oddest and most considerable detection" was the discovery of the diverse refrangibility of light. It was sent to Oldenberg on the sixth of February and was read before that illustrious company on February eighth, resulting in a vote of "solemn thanks of the meeting to the author for his very ingenious discourse." It was immediately printed in the Transactions. Then the trouble began. You all know the history of the Royal Society. It was formally organized in 1660, but it had existed as an informal group or "invisible college" for fifteen years, meeting weekly, usually at the Bullhead Inn in Cheapside, for the purpose of discussing the experimental philosophy and incidentally for meat and drink and good cheer. The men who constituted these first groups of organized science were not long-faced specialists or academicians in the continental sense; they were convivial Englishmen and men taken from all walks of life; all of them were amateurs in science except a few holding chairs in Gresham College and elsewhere. Science was a city waif

—it was almost a stranger at the universities and remained so until three or four generations ago. These men loved heavy meat and much drink and hard and strenuous reasoning and intellectual combats. It was the secretary's job to bring forth discussion, differences of views, defence and offence and as much controversy as possible. Oldenberg was an artist in this activity. Huygens, Linus and Lucas of Holland were in the opposition, and Lucas was the schoolfellow who administered the second blow in the stomach that Newton received. The scene in the churchyard was repeated, Oldenberg played the part of the schoolmaster's son, and mild and peace-loving Newton was again forced to try to drag his antagonist over the tombstones and rub his nose on the church wall. But it was a profitless performance. It was more than a scrap between corpuscular and undulatory theory. Newton affirmed that the length of the spectrum was five and one-half times its width. Lucas claimed it was only three and one-half times as great. If the contenders had only calmed their excitement and noted that one used flint glass and the other crown glass, the great discovery of the achromatic lens might have resulted and the science of optics would have been put ahead eighty years. A bitter churchyard scrap does not work well in science. It neither benefited Newton, Hooke, Huygens nor Lucas and the contestants became so set and immovable that it helped neither the corpuscular nor the undulatory theory—all the scientists were wrong part of the time and some of them were wrong all of the time. Newton nearly quit philosophy. "I intend," he wrote Oldenberg, "to be no farther solicitous about matters of philosophy." This was not a temporary resolution, for nearly a year afterwards he wrote, "I see I have made myself a slave to philosophy; but if I get free of Mr. Linus' business, I will resolutely bid adieu to it eternally," and that "mathematical speculations are at least dry if not somewhat barren." He tried hard in 1675 to get a fellowship in law. He had only one competitor, but Newton's friend and patron, Dr. Barrow, Master of Trinity, decided in his competitor's favor, thus sav-

ing Newton to science. Newton was bitterly disappointed. He took refuge in studies in alchemy, wasting his days and nights in the search for the universal elixir and the transmutation of the metals. He tried to resign from the Royal Society, but they made him a member without dues. He knew he must soon lose his fellowship, for the time was expiring when he could hold it without taking holy orders. But in 1675 he was saved again for science by being appointed Lucasian Professor of Mathematics with a special dispensation from the King to hold the chair and fellowship without taking holy orders.

It is obvious that there were two Newtons—the normal Newton, the serene and gentle and silent Newton, and that other Newton that was only aroused by blows dealt directly to him. This last Newton was easily tormented into profound agonies of suffering, his very sensitiveness and sense of justice aiding in bringing forth the enraged and fighting and abnormal Newton.

Newton did not turn away from alchemy and return to his gravitational studies until 1684. In the meantime Picard had shown that the earth's radius was about 3,960 miles and not 3,450, the value taken by Newton. After using this new value to correct his former computation, Newton wrote: "The moon appears to be kept in her orbit purely by the power of gravity." According to Cajori the delay in the verification to Newton's satisfaction of the law of universal gravitation may have been due to the difficulty Newton experienced in solving the problem of the mutual attraction of two uniform spheres, which he did not clear up until the summer of 1685. Then Newton's real job began. The years 1685, 1686 and the early part of 1687 will ever be memorable in the history of science. It was in these years that the *Principia* was composed and given to the world. You must read all about Newton, his letters and personal notebooks to understand the conditions under which this great work was produced.

Each age seems to have an outstanding problem to serve as a challenge to its scholars. This is the age of the Mickelson-

Morley experiment. The challenge of this unsolved problem has produced more good electrodynamics and more good mathematics than thousands of successful investigations. The Mickelson-Morley dilemma of the early Greek geometers was the problem of the squaring of the circle. These problems brought forth more good geometry than all the solvable problems of the day. The Mickelson-Morley dilemma of Newton's day was the problem of the moon's motion and for more than a century after his time it was the challenge that called to the contest the great men of those days—Claraut, MacClaurin, D'Alembert, Euler, Lagrange, Laplace. These giants were developed in their strength by the problem of the moon. The problem had had in Newton's day a most practical appeal. If the complex course and irregular motions of the moon could be brought under a system or systems of causes, then accurate tables could be computed and the position of a ship at sea could be determined. It seemed hopeless in those days to perfect a timepiece that would keep good enough time through long sea voyages so that longitude could be known. By the tables of the moon of Newton's day the longitude could not be determined within thirty minutes. About five of the irregularities in the moon's motion had up to that time been discovered, two of them by Tycho Brahe, but of course no cause was known. Galileo explained the libration in latitude, and Newton promptly explained the libration in longitude. But why should the moon's speed vary in its quadrants? What effect will the changing distance from the sun have on these quadrantal speeds? Why should the perigee continuously advance? Does the moon's orbit change shape as the earth passes from the near position to the far position from the sun? Does the plane of the moon's orbit rock back and forth as the earth carries it about its own annual course? What effect has the oblateness of the earth upon the motion of the moon? These and many other questions coursed through Newton's brain as he contemplated the problem of the heavens. If the principle of universal gravitation could explain and tie together all

these movements and all of the irregularities of movement, then there was hope that accurate tables of the moon could be prepared, that the seas could be securely navigated, and that truly a great service would have been rendered his race. The plea of the practical was strong with Newton, as it was with many other great scientists—for example, Helmholz and Lord Kelvin. *Practical* is a very poor and much abused word. To Lord Kelvin the Atlantic Cable and his new compass for iron ships were merely instances of services rendered to his fellow beings, and to Newton, the determination of longitude at sea meant safe journeys, and the stimulation of intercourse and the spread of civilization among the races of men. The "practical" often implies more altruism than the thoughtless are willing to admit.

Newton was able to print in the lunar theory of the *Principia* a fairly complete explanation of the variation, of the parallactic inequality, of the annual equation, of the retrogradation of the nodes, of the progression of the line of apsides, of the evection or variation in eccentricity, and of the variation in the inclination. Newton left an unpublished manuscript in which he had accounted for the entire motion of the perigee. No progress was made in explaining the secular acceleration until the time of Laplace.

The *Principia* must be viewed, therefore, not as a mere book of science, but as an epic whose story is the sufficiency of the laws of mechanics and the principle of universal gravitation to explain all of the motions and all of the irregularities of the motions in the phenomena of the heavens. It is the most profound story ever put forth by human genius. Laplace, in his oft-quoted words, says: "The number and generality of Newton's discoveries relating to the system of the world, the multitude of original and profound views which have been the germ of the most brilliant theories of the geometers of the last century, will assure for the *Principia* a pre-eminence above all other productions of the human intellect." The first two books of the *Principia*, if translated from their geometrical form into the language and symbolism of twentieth-century

analysis, could hardly be distinguished from a modern text on dynamics of a particle, so little have two centuries added to the work of the master. As one enters the last part of the treatise, he is overwhelmed by the uncanny intuition shown in the treatment of almost every topic. The fundamental problem of the mutual attraction of two uniform spheres, the motions of the planets about the central sun, the motions of the four satellites of Jupiter and of the moons of Saturn, are brought into the orderly march of the epic. Then the climax of the story is reached in the analysis of the complex motions of the moon. Next, by a reworking of some of the material of the lunar theory, the phenomena of the tides are explained, and, by the very ingenious device of considering the belt of excess material in the earth's equatorial zone as a continuous set of moons attached to a spherical earth, the precession of the equinoxes is accurately accounted for. Throughout all these many chapters of the story, gravity with its law of inverse squares serves as the overpowering fate that sweeps in its iron control all the events to their appointed destiny. The human intellect had never before reached so noble a conception of the nature of things.

It is interesting to speculate as to the progress of mathematics in the past centuries if the earth had not possessed a moon, or had possessed only a very small or a very distant moon. Then the great challenge of the problem of the complex motions of the moon would not have existed, and it is quite certain that the advance in mathematics as well as the advance in all of the exact sciences would have been materially less. The moon, instead of contributing to lunacy, as held by ancient superstition, has been a major cause in the evolution of the human intellect.

Newton worked at the composition of the *Principia* with an enthusiasm and a speed that was little short of fanatical. From 1683 to 1689 he employed a secretary, Humphrey Newton, to copy papers and prepare matter for the printer, etc. From this intimate source we know much about his personal habits. Humphrey says: "I can not say I ever saw him laugh

but once . . . his carriage was meek and humble . . . I never knew him to take any recreation or pastime either in riding out to take the air, walking, bowling or any other exercise whatever, thinking all hours lost not spent on his studies—so intent, so serious upon his studies that he ate very sparingly, nay oftentimes not at all, so that going to his chamber I have found his meal untouched, of which when I reminded him, he would reply 'Have I?' and then making to the table would eat a bite or two standing, for I cannot say I ever saw him sit at table by himself . . . he very rarely went to bed until two or three of the clock, sometimes not until five or six, lying about four or five hours—he very seldom went to Chapel, that being the time he chiefly took his repose, as for the afternoon, his earnest and indefatigable studies retained him, so that he scarcely knew the house of prayer . . . in his chamber he walked so much you might have thought him to be educated in Athens among the Aristotelian (peripatetic) sect . . . when he has sometimes taken a turn or two he might make a sudden stand, turn himself about, run like another Archimedes with an Eureka, fall to write on his desk standing . . . his behavior was mild and meek, without anger, peevishness or passion, so free from that, you might take him for a stoic."

The *Principia* was issued by the Royal Society about midsummer of 1687. The funds for its printing were really furnished by Halley although the Society had originally promised to bear the expense. The *Principia* is divided into three books. The first book begins with the laws of motion, and discusses the motion of bodies in free and constrained orbits. The second book treats of bodies moving in resisting media or oscillating as pendulums. The third book treats of the system of the world, the quantity of the lunar irregularities, the quantity of the tides, the precession of the equinoxes and the orbits of comets. This great work, as might have been expected, excited a warm interest in all parts of Europe. A copy could scarcely be procured by 1691 and at that time a new edition was already contemplated. While it is probable that not more than twenty people in England could under-

stand it, nevertheless it became the subject of parlor conversation and made great fame for its author. It was much like the popular interest of the present day in the work of Einstein. The universities, however, in the beginning were little influenced by the new system. The Scottish universities, St. Andrews and Edinburgh, were the first to teach the philosophy of the *Principia*. Oxford, with characteristic conservatism, continued to teach the vortex theory of Descartes for many years. Even Cambridge can hardly claim to have been an early supporter of the *Principia*. While Newton was at Cambridge, he practically had no hearers at all; often not a single person would show up at his lectures. When he left Cambridge in 1696 the *Physics* of Rohault was still in use as a text, but fortunately they used Clark's Latin translation of the French text, which contained copious notes in which the ingenious translator explained, without bias or controversy, the views of Newton on the principal objects of discussion, so that they virtually constituted a refutation of the text, but the student, naturally inclined to radicalism, would look into the notes, and of course contend for that view. Hence, we may say that the Newtonian philosophy first entered Cambridge surreptitiously and under the protection of the Cartesian philosophy.

But life began to change for Newton. He had been one of a commission of three to defend the rights of the university against the encroachments of the King. This led in 1689 to his election to represent the University in Parliament. This meant, of course, that he took up his residence in London, where a number of events transpired. He made the acquaintance of the high cost of living and consequently the desire for a better income. He acquired the great personal friendship of Locke. He met Huygens for the first time at an interesting meeting of the Royal Society, where Huygens discoursed on gravity, which Newton knew and Huygens did not, and Newton discoursed on double refraction, which Huygens knew and Newton did not.

It was also during Newton's service in Parliament that his

mother passed away. The loving care with which she had nursed his frail infancy, and the mother's intuition through which she had discerned his budding genius, and the personal sacrifices she had made to send him to Cambridge, had led on his part to a devotion more than filial. For her it had been reward enough to have lived to follow with a mother's pride his rise to fame. Newton dropped his duties and his studies to attend at her side. He sat with her through all the nights and administered to her with his own hands until the end came. His mother did not hold a second place in his affections.

Not long after this, in 1690, when Newton returned to Cambridge from Parliament, it was to undergo the most distressing experience of his career. It was nothing short of a complete nervous breakdown. He was sleepless and melancholy and broken in health. He wrote the most inexplicable letters to some of his friends and then afterwards had no recollection of having written them. He had always been deeply religious, but he now took up the weird and fanatical part of religion and wrote astonishing treatises on the Prophecies of Daniel and the Apocalypse of St. John. Just before this breakdown Newton was occupied with the profound and difficult problem of the lunar irregularities. Newton said that his head never ached but when he was studying that subject, and pain in plenty must have been the lot of one who was, in fact, trying to attack the famous problem of three bodies with the meagre mathematical equipment of those days.

He had made the intimate friendship at Cambridge of Charles Montague, a young man of sagacity and charming personality. Montague soon went to London where his rise to power and fame was rapid and spectacular. He became the trusted servant of the King, rose to the First Lord of the Treasury and was made Lord Halifax. In 1696 he appointed Newton Warden of the Mint at a salary of eight hundred pounds and in 1699 Master of the Mint at a salary of fifteen hundred pounds. Newton, of course, moved to London, where he maintained quite an establishment on Jerwin

Street and later on Martin Street, with six servants and a coach befitting his rank. His home was presided over by a niece, a young woman of wit, beauty and accomplishments, Catherine Barton. She was a famous beauty of her time and her charm and gaiety called forth the praise of the poets, and the adoration of a train of suitors. It was no trouble to Newton, therefore, to entertain the best company in London at his establishment. She seems to have been the mistress of Lord Halifax, who left her an annuity and an handsome estate besides. She later married a personal friend of Newton, John Conduitt, M.P., and an important man of the day, who succeeded Newton at the Mint, and whose letters and writings are the source of much personal knowledge about Newton.

Newton's honors now came thick and fast. In 1703 he was elected President of the Royal Society, which place of honor he held for a quarter of a century. He became the confidant of Prince George of Denmark—the Prince Consort. In 1705 the Queen in great splendor paid a visit to Cambridge where, agreeable to ancient custom, the Congregation of the Senate conferred degrees upon all persons nominated by Royal Command, and the Queen, holding court at Trinity Lodge, conferred the order of Knighthood upon Sir Isaac Newton.

At the date of his nervous breakdown at the age of fifty, Newton's scientific work was practically over. From 1693 on he continued to ponder over the problem of the moon and was constantly hurrying Flamstead, the Astronomer Royal, to furnish new observations. The second edition of the *Principia* was begun by Cotes in 1709 and brought out in 1713. The third edition was in charge of Dr. Pemberton and did not come from the press until 1726. In both of these editions, Newton made important revisions, but no major contributions to theory were involved.

Then in 1710 that distressing controversy with Leibnitz broke out, one of the most disgraceful episodes in the history of Science. In 1687 Leibnitz had published his *Differential Calculus*. Newton's method of fluxions was known only to a few of his friends. Although Newton made use of the method

of fluxions in composing the *Principia,* the propositions in that work were demonstrated by the methods of the ancients, shortened only by the use of the method of limits for that of exhaustions. He made absolutely no voluntary public communication concerning the method of fluxions. Even so eulogistic a biographer as Brewster does not find it easy to penetrate into the motives by which he was actuated. If his object was to keep possession of his discoveries until they could be further perfected, we cannot admire either his good sense or his prudence. If he wished to retain to himself his own methods as private property, we cannot too strongly condemn so selfish a decision. If he withheld his labors in order to avoid disputes and contentions, he adopted the very worst method of securing his tranquility. So he staged another churchyard fight all over again. The kick in the stomach that aroused Newton was an attack of Leibnitz in 1710 on the theory of gravity, wherein he accuses Newton of introducing occult qualities and miracles into philosophy. We must spend no time over this disgraceful brawl which raged for over seven years. The attack on Leibnitz was personal rather than scientific. A committee of the Royal Society (I. Newton, President) was appointed to investigate and report. Most members of the committee did not know enough mathematics to understand what they were talking about. Of course, no one friendly to Leibnitz was on the committee. They were selected for their fighting qualities, and not for expert knowledge. They proceeded in the attempt to drag Leibnitz over the tombstones and rub his nose against the church wall. Newton aided actively and the whole fight deserves only to be forgotten. The world has now decided the matter. Both have been accorded equal honors as inventors of the calculus. Newton undoubtedly has a claim of priority, but Leibnitz gave his work to the world, fully and without delay. In any case the honors, while great, are of secondary rank; what honor there might have been has been dissipated by the disgraceful international quarrel.

It is not easy to believe that Newton did best when he for-

sook scientific work so early in life and took up a career in the service of the Crown. One of the rarest constructive intellects the world has known, a genius of two thousand years, was diverted from science at the age of fifty-four. Newton himself had no doubt about that matter at all. He thought it fully as noble to serve his sovereign as to serve philosophy and he seems to have taken the greatest personal satisfaction in his new career. He was not fifty when he went stale, and he never fully recovered his scientific ambition. Unless it would have been possible for him to have advanced theoretical mathematics by his own unaided power to the stage it reached with Euler, Laplace and Lagrange, he could hardly have contributed much more to mechanics, especially to the crucial problem of the moon. If those days and nights spent in the search for the universal elixir and the transmutation of the metals and the Prophecies of Daniel could have been diverted to mathematics, perhaps he could have put his age ahead another generation. But I suppose that the universal elixir seemed no more visionary than universal gravitation. All mysteries look alike to the eyes of ignorance. Robert Boyle, one of the most hard-headed men of his day, also wore himself out in alchemy and in fruitless religious speculations.

Newton took all of his duties very seriously: scientific, official and social. He ran for Parliament again, but was defeated. He was thoroughly interested in promoting the welfare of the Royal Society. He made strong representations to Parliament which led them to offer a prize of 10,000 pounds for accurate tables of the moon. No award was made from this fund until 1770, when 3,000 pounds went to the widow of Tobias Mayer. These tables were never found to be off more than 75 seconds, hence three hundred pounds were awarded to Euler on whose formulas the practical work of Mayer had been based. The lunar theory was deemed to be complete when Laplace thought he had explained the secular variation, but even this was not final, for the problem went back to Trinity College, Cambridge, and was first solved correctly by Adams about 1850. Finally with rare ingenuity

and sagacity an American, G. W. Hill, developed the lunar theory to near perfection so that with the continuation of Hill's work by E. W. Brown, we can now say that the problem of the moon is solved. It seems that Newton's law of gravitation does not need to be modified or supplemented to explain fully all known motions of our satellite.

It is a fact, therefore, that the Newtonian theory entered this century with every mechanical fact in the solar system accounted for except the motion of the perihelion of Mercury. To explain this, however, it is now known that the Einsteinian theory must be substituted for the Newtonian. The modern philosopher shows us that the ancient conception of space and time, as adopted by Newton, constitutes a logical impediment to the explanation of the very thing set up as the universal principle—namely gravitation. In the *Principia* that Einstein might write, the conceptions of space and time each yield to the other so that gravity itself may be included in their frame. Newton, nevertheless, laid the basis of modern physics, most of whose concepts are due to him. Some of these, such as mass, inertia, force, are retained, but enlarged and given a richer content. Others, such as absolute space and absolute time, which he made the base of classical mechanics, are not now acceptable in physics. Science tends continually to bring a wider and wider region of experience within its domain, but the newly acquired provinces tend to make new provinces even out of the old ones. Electricity is one of these new provinces, entirely unknown to Newton, and this new domain has changed all the old domains. And the theory of quanta and other concepts of discontinuity are new, and are changing much of the old. We must not even say that the quantum theory is a return to Newton's corpuscular theory, for Newton had no adequate conception of energy and his corpuscular theory could not stand up before an undulatory theory. The controversy with Hooke and Huygens has no modern bearing—it was a personal and not a scientific debate—it was only a churchyard brawl. Physicists are hardly justified in speaking of the revival of the corpuscular theory

—to do so is to overlook the ever changing concepts in which both theories are imbedded.

Science is fast forcing us to see that time and space are but subjective conceptions, thinner even than the stuff that dreams are made of. If none but observable factors are to be considered as in causal dependence, we must go far in revising the list of realities. We are taken back to the doctrines of Pythagoras, who made the first outspoken claim for the place that abstract thought must hold in solving the mysteries of phenomena. Pythagoras was a supergenius. He saw that the comprehension of the world about him was to be sought in the revelation given by mathematics. In an outburst of intuition he proclaimed that "the nature of things consists in number." This marvelous dictum by implication relegates space and time to secondary positions of subjective content, and leads eventually to the doctrine of Einstein, wherein the concept of space and time yield to each other to make a new frame for phenomena. Mathematics has taken on new power and is fulfilling the prophecy of Pythagoras by arraying natural truth in the ordered ways of number. In this day the different sciences are seen to be but different phases of mathematics: Physics is the noisy part of mathematics; chemistry is the smelly part of mathematics; biology is the mussy part of mathematics.

That frail infant born in 1642, so small that he could have been placed in a quart measure, lived to the ripe age of eighty-five. He was past eighty before he began to suffer seriously from the torments of age. He had moved from Chelsea to Kensington to ease his infirmities and there on March 20, 1727, he passed away. On Tuesday, March 28, his body was borne to Westminster Abbey and buried near the entrance to the choir on the left side. At that place there has been erected a monument to one who, of all those of the Abbey, least needs a monument, and thereon, in well-poised Latin words, is the eulogy to one who least needs praise: "Who by a vigor of mind almost divine, the motions and figures of planets, the paths of comets, and the tides of the seas, first demonstrated."

THE PHYSICAL PLANT OF THE UNIVERSITY OF NORTH CAROLINA.

BY THOMAS C. ATWOOD.*

The building of the University of North Carolina was started in 1793 when its first structure, "Old East," was begun, the first building to be erected on any State university campus in this country. This was quickly followed by "Person Hall" and "South," these three forming the original group, completed in 1798.

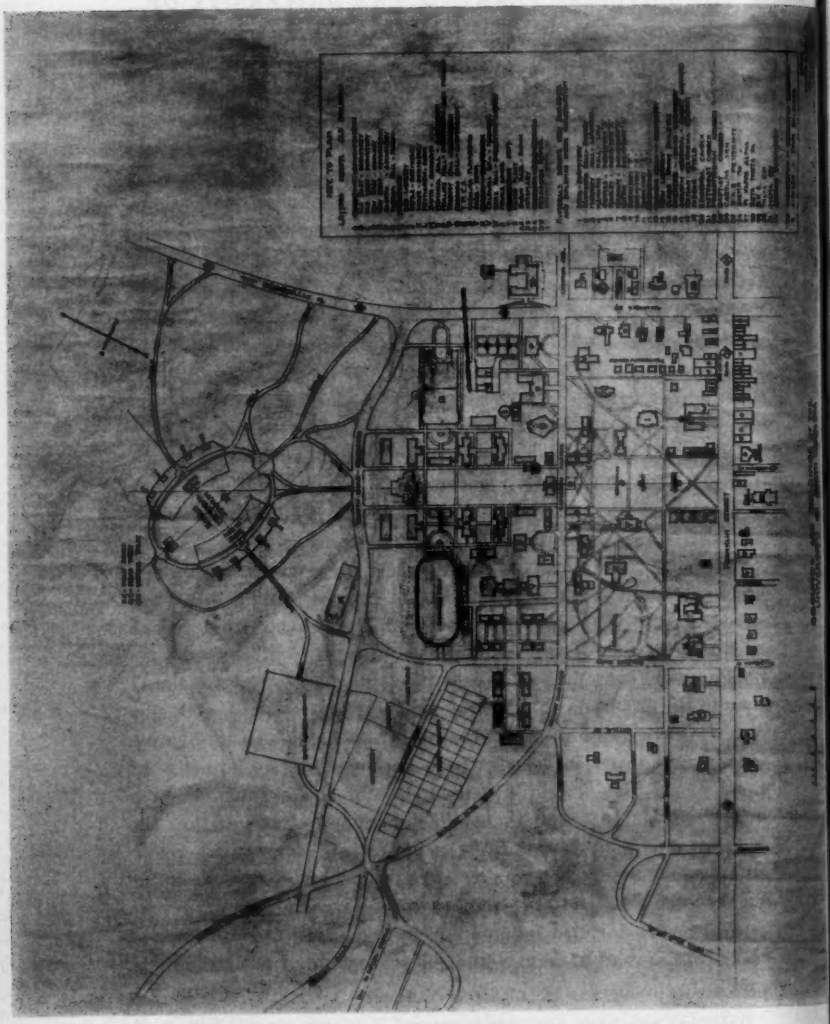
From that time until 1920 additional buildings were added as needs grew and means were available, the needs usually outrunning the means, as is generally the case, and then the University group included some twenty-nine buildings, divided as follows: 1 library, 2 auditoriums, 8 classroom buildings, 4 combination classroom and dormitory buildings, 7 dormitories, 1 infirmary, 1 gymnasium, 1 dining hall, 1 president's house, 1 Y. M. C. A. building, 1 power plant, 1 laundry.

In these buildings were available about 100 classrooms, lecture halls and laboratories, and 235 dormitory rooms.

All but two of these buildings were of non-fire-resistive construction with brick walls and wood interior, and many were poorly built. Few had any provision to stop the rapid spread of fire or means of safe exit in case of fire.

Since 1920 this has all been changed. Not only have many new buildings been built, all of modern, fire-resistive construction, but virtually all of the old buildings have been renovated, some made practically safe for occupancy by the addition of brick stair towers and fire escapes and the closing of open stairwells, some having their interiors renewed except that the wooden floors and partitions remain, and some made completely modern by the removal of everything except the outer brick walls and the building up of a new concrete structure within. All dormitories now are so reconstructed as to resist the rapid spread of flames and all are provided with adequate and safe means of escape in case of fire. Of course, this ap-

* Atwood and Nash, Inc., Architects and Engineers, Chapel Hill, N. C.



plies only to the old dormitories as all new dormitories are of fire-resistive construction and have enclosed staircases with smoke corridors as well.

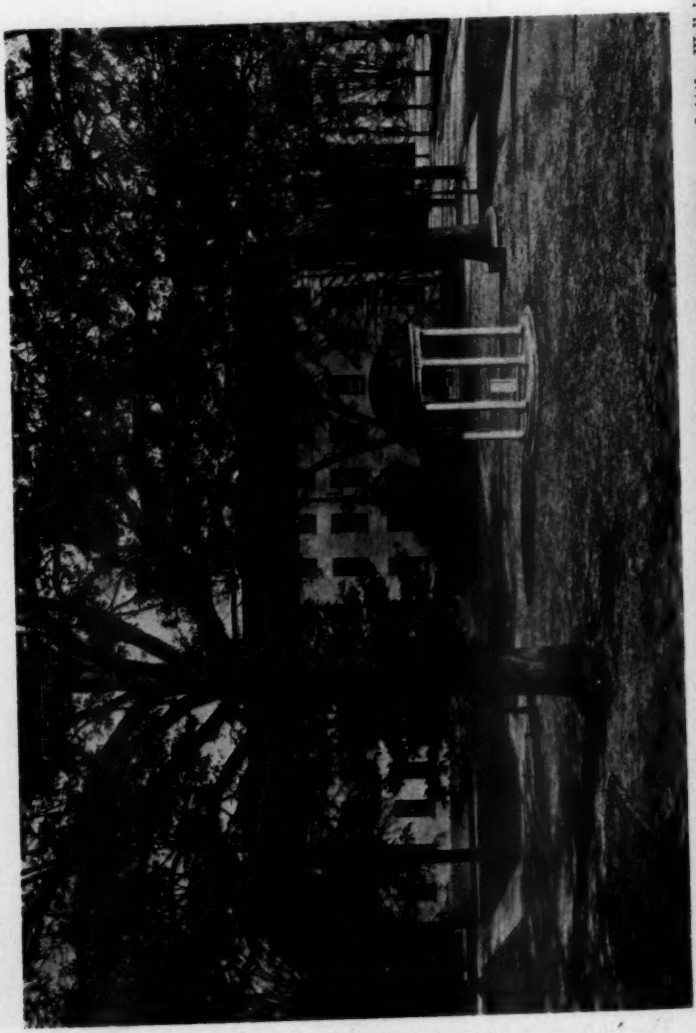
In 1920 the University buildings were not only inadequate in number and capacity but some had fallen into such a state of disrepair as to be almost useless, and poor acoustics, inadequate heating, etc., made others difficult to use. The University authorities were thoroughly alive to the conditions and determined to wage a state-wide campaign of education to bring the problem before the people in such a way as to insure favorable action by the legislature on their request for a building fund of $5,585,000 to be expended in five years. The campaign was practically successful, that is, the legislature of 1921 authorized the beginning of the construction program and appropriated $1,490,000 for this purpose, placing the responsibility for the expenditure of the money on the Trustees of the University. From then on, progress has been fairly rapid. The legislature has appropriated to date the sum of $5,140,000.

The original scheme contemplated providing a university plant capable of caring adequately for a student body of 3,000 which it was anticipated might be reached by 1930. The rate of growth has been slightly greater than this, the registration in the fall term of the present college year being 2,770, showing that the estimates made were conservative.

The University plant now built and provided for in the present appropriation comprises 46 buildings, divided as follows: 1 administration building, 1 library, 2 auditoriums, 16 classroom buildings, 17 dormitories, 1 infirmary, 2 gymnasiums, 1 dining hall, 1 president's house, 1 students activity building, 1 power plant, 1 laundry, 1 maintenance building.

In these buildings are available about 200 classrooms, lecture halls, laboratories, etc., and 700 dormitory rooms as well as ample quarters for the administrative offices, extension department, and service departments. All combination classroom and dormitory buildings have been eliminated.

The University has also a number of dwellings for housing



"Old East" Building—first building erected on a state university campus in the United States, and "the Well."

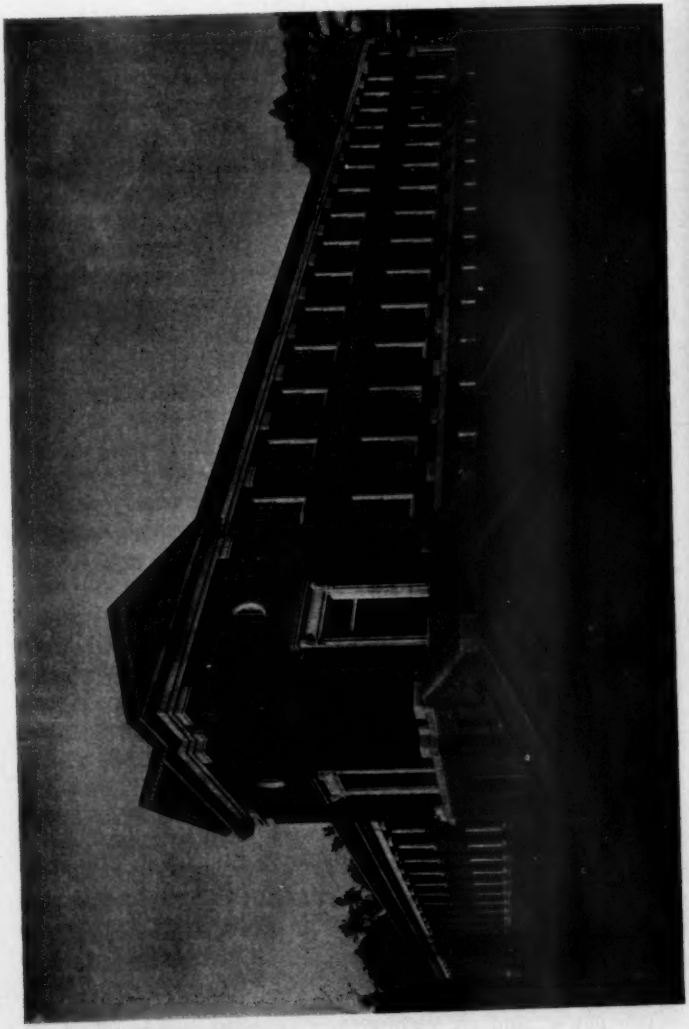
new members of the faculty until they can provide residence for themselves. A fine arboretum is provided for both study and pleasure. The outdoor athletic side of student life is cared for with 3 athletic fields, 40 tennis courts and a stadium. The Carolina Playmakers have an indoor and an outdoor theatre for their work.

The University now possesses a thoroughly up-to-date plant, still inadequate in some respects to present needs, it is true, and still without unused space giving provision for expansion, but nevertheless a fine workable plant, and when a few of the more pressing needs have been filled it will be one of the best balanced plants in the country.

It is hardly necessary to describe in detail the dormitories and the general classroom buildings, but special attention may be called to the Chemistry Building, the Law Building and the Library, all being special buildings designed to meet the particular needs of those departments.

The Chemistry Building, named Venable Hall, in honor of Dr. Francis P. Venable, formerly President of the University, is about 200 feet square, and covers nearly an acre. The front of the building, three stories high, contains library, five class-rooms, general office, museum, and laboratories of physical and electro-chemistry. The south wing, two stories high, contains 38 small rooms for staff-offices and private laboratories, thus providing each member of the staff and each graduate student with an individual laboratory. The court within the arms of these two sections contains a one-story structure, with factory, sawtooth roof, and has twelve large laboratories for general chemistry, analytical chemistry, organic chemistry and a storeroom. Industrial chemistry is provided with a room of about 1,600 square feet area and 25 feet high. It has a traveling crane overhead to lift and move about apparatus of semi-commercial size. Adjoining this room are four small rooms for control work, a dark room, a transformer room, and rooms for the control of the ventilating system. At each desk in the laboratories are outlets for gas, air, steam, water, and electric power, and an opening into the exhaust ventilating ducts. A large lecture room, seating 256, is lighted from

"Old East" Building—first building erected on a state university campus in the United States, and "the Well."



Venable Hall—the Chemistry Building.

above and has special ventilation. The ventilating system is worthy of special note as it has proven most successful. It is a dual system, a large fan forcing 65,000 cubic feet of air per minute through the distributing system to the various laboratories, while exhaust fans in these rooms remove 25% less than is forced in, all exhaust being through the hoods over the tables, each student having an exhaust hood opening within the space allotted to him. All the general laboratories are flooded with north sky light through the sawtooth roof construction. The site of this building was chosen especially with a view to future expansion, room being available for doubling or even tripling its size.

The Law Building, named Manning Hall in honor of Dr. John Manning, is a two-story-and-basement building containing two large lecture halls, eight smaller rooms for class work and offices, the law library and stack room and a large general meeting room for the use of the students when off class. As befits a building housing a fine graduate school, the interior finish of this building is of higher class than the regular classroom building, oak trim being used throughout, with terrazzo, linoleum and oak floors in the lobby, library and rooms. Special furniture was designed to fit the building and its needs.

Venable Hall—the Chemistry Building.

The new Library building now under construction is based on an up-to-date program of requirements. This program was developed over a period of two years' study on the part of the librarian and the architect. Careful comparisons were made among the plans of existing university libraries, and visits made to libraries all over the country with the object of checking up the practical working of various theoretical plans.

Of course, the local needs of the University of North Carolina have been the chief consideration, in developing the library plans. Beside the stack rooms the plans provide for

1. A suite of reading rooms 200 feet long by 48 feet wide extending entirely across the building at the second floor level.
2. A large delivery room centrally placed adjacent to the stack room, library work-spaces and the reading rooms.

3. A library school.
4. Extension department.
5. Reference reading department.
6. Sociology department, etc.
7. Rooms for special collections.
8. Treasure room.
9. Offices—administrative and executive.
10. Uncrating room and storage.
11. A series of special study or seminar rooms.
12. Within the stack space next to the windows are placed alcoves or "carrels" for the use of especially qualified graduate students.

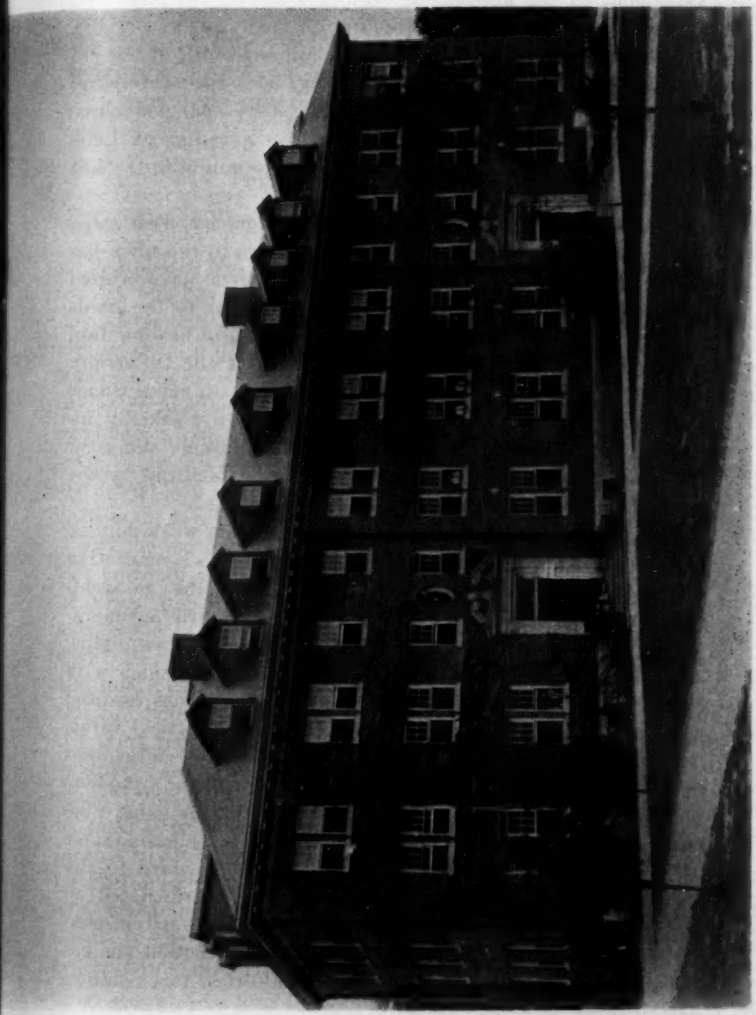
The architects have sought to give the building a sufficient degree of architectural finish and character so that in the years to come it will not become out-classed by advancing standards of architectural design.

They have sought, also, to make a plan that will admit of almost indefinite expansion, not only in book-storage but also in the reading rooms, special collection rooms and study space.

The Kenan Memorial Stadium is a gift of Mr. W. R. Kenan, Jr., and was built during 1927. It has a seating capacity of 24,000. The seat banks are two crescents built into the sides of a valley, with the concrete steps supported directly on the ground. There are 41 rows of seats, each side being approximately 500 feet long. The seats are of wood, supported above the concrete. At one end of the field is a Field House, containing locker, rubbing, shower and locker rooms in duplicate for the opposing teams, quarters for the officials and, in the second story, sleeping quarters for the athletes. Particular attention was given to the selection of the site and to the designing of the structure so as to take every advantage of the site, and the result has been stated by many to be the "most beautiful stadium in America."

In type of architecture, the new buildings have returned to the Georgian Colonial, the period in which the original buildings were designed and built.

To meet the needs of the growing University it was especially necessary that a "block plan" or scheme of future de-



Mangum Hall—Dormitory "D."

velopment in the location of buildings should be made and this was done early in the program.

A Greek-cross-shaped campus was laid out south of the old main campus, with the South Building, used for administration, dividing the old campus from the new. All new classroom buildings are laid out to be within a radius of 1,000 feet from the center of the campus, so as to minimize the lost time between classes.

While this expansion of the University plant has been going on, a notable increase in the public buildings in the town has taken place. The four principal denominations have erected fine new church plants particularly to minister to the needs of the students, a handsome modern hotel, the Carolina Inn, has been built, to care properly for guests of the University as well as relatives of the students, delegates to conventions, etc. The student housing facilities have been markedly increased by the building of a number of handsome and commodious fraternity houses, and the boarding facilities by the establishment of several excellent cafeterias.

The method of handling the new construction work may be of interest. The designing and supervision of all construction since 1920 has been done by Atwood and Nash, Inc., as architects and engineers for the University, and this firm has maintained an office on the campus which has proved of great value, as it enabled all buildings to be designed in close touch with the departments which were to occupy them, and has resulted not only in securing buildings of the greatest practical value, but in the elimination of waste space and with consequent economy. McKim, Mead and White are consulting architects for the University. The construction has for the same time been handled by T. C. Thompson & Bros. on a fee basis under a special contract which causes all savings to inure to the benefit of the University so that the money appropriated by the legislature is made to go as far as possible in actual construction. This method of handling the construction has enabled the costs to be kept low, the dormitories, for instance, costing only $900 per student.

MODERN EDUCATIONAL TENDENCIES AS AFFECTING THE PREPARATION OF ENGINEERING STUDENTS.*

BY ELTING H. COMSTOCK,

Professor of Mine Plant and Mechanics, University of Minnesota.

In Bulletin No. 1 of the Investigation of Engineering Education, published by this Society, I find on page 8 the following statement, "When we turn, however, to the quality of preparation, a different picture is presented. There is ample evidence to show that preparation for engineering courses is seriously lacking in those elements of definiteness and thoroughness which are so essential in the training of the engineer." In this statement I most heartily concur, nor do I believe that my concurrence is due, as has been charged, to increasing age, or lack of sympathy with modern youth.

For the past twenty odd years it has been one of my duties, as Chairman of the Students' Work Committee in the School of Mines and Metallurgy at Minnesota, to endeavor to learn why students fail. I have talked with them, in many cases with their high school teachers, with their parents and in addition have endeavored to learn something of modern educational tendencies through rather extensive reading.

I think most of us will admit that a decided change in the quality of preparation has appeared in the last ten or fifteen years. This paper is an attempt to account for this change in the light of modern educational tendencies. I regret that time forbids my presenting, somewhat in detail, the changes in instructional methods which have been introduced since the days when the main duty of the teacher was to instruct his pupils in the art of reading and to listen to the parrot-like repetition of memorized answers.

* Presented at the 35th annual meeting of the Society, University of Maine, Orono, June 27–30, 1927.

About one hundred twenty-five years ago, Pestalozzi, in developing the idea of Rousseau that sense impression was "the only true foundation of human knowledge," declared, "that education is an individual development, a drawing out and not a pouring in; that the basis of all education exists in the nature of man; and that the method of education is to be sought and constructed." *

Much improvement resulted from his efforts and his ideas were taken up by various educators, among whom Herbart may be mentioned as having contributed much. "Interest he held to be of first importance as a prerequisite to good instruction. If given spontaneously, well and good; but, if necessary, forced interest must be resorted to. Skill in instruction is in part to be determined by the ability of the teacher to secure interest without resorting to force on the one hand or sugar-coating of the subject on the other." †

He also clearly presented the idea that new knowledge could best be acquired by making it develop from that already in the minds of the pupils. He recognized, however, that in the acquiring of certain facts there is no royal road and that they must be "committed to memory."

Various other men added their bit, but it remained for John Dewey, about the beginning of this century, to furnish another contribution to the theory of education. His idea was that education involved, "not merely learning, but play, construction, use of tools, contact with nature, expression and activity; and the schools should be a place where children are working rather than listening; learning life by living life and becoming acquainted with social institutions and industrial processes by studying them. The work of the school is in large part to reduce the complexity of modern life to such terms as children can understand and to introduce the child to modern life through simplified experiences." ‡

With these ideas as starting points, modern educators have developed a vast number of theories and methods, many of

* Cubberley, "The History of Education," p. 747.

† *Ibid.*, p. 761.

‡ *Ibid.*, p. 782.

them conflicting. They agree in the main that interest shall be the fundamental inspiration in the acquiring of knowledge, that material should be presented only as it meets a need or fits the experience of the learner and that as far as possible, the schools should endeavor to present to the pupils a comprehensive view of life, the better to fit them for taking their positions as citizens of the community. Instead of mastering a few of the fundamental subjects, the material offered in these should be cut down to make room for a knowledge of more subjects.

The following statements give the new viewpoint:

"For illustrative purposes, let us consider the organization of the conventional secondary-school curriculum. That curriculum was composed for the most part of foreign language, mathematics, abstract science, history, and English. The purposes which dominated this institution were those of formal discipline and preparation for college. That the older theory of mental discipline rested on an insecure psychological foundation or that the requirements of the college reflected the conditions of a distant past, is a matter of little consequence here. The fact to be observed is that the organization of subject matter was derived largely from these purposes. In the meantime, with the extraordinary expansion of the public high school its purposes have been transformed. Whereas in the past the aim of this institution has been to prepare a highly selected group of students to pass examinations in Latin, French, algebra, geometry, ancient history, and physics, today its function is to equip the great masses of boys and girls of adolescent age for effective and relatively immediate participation in the life of society. That an organization of subject matter adapted to the achievement of the former purposes is also suited to the attainment of the latter is unthinkable. If the high school is to be an effective instrument in giving the ordinary adolescent insight into the natural and social world about him and in developing in him a sympathetic understanding of the major problems and issues of contemporary life, the curriculum should be organized with these ends in view. While experiment may show the wisdom of retaining certain of the lines of demarcation which have been inherited from the past, it seems altogether likely that many of those lines will have to disappear. The natural expectation is that the materials of instruction should be or-

ganized about the accepted purposes of the institution. If we would have the student gain insight into the problems of citizenship, we should seemingly bring to him from all available fields of knowledge the materials which would illuminate those problems. In developing desirable appreciations, attitudes, and ideals a similar course should be followed. While the experience of the past should by no means be lightly discarded, that experience, when gained in a different setting, should not be permitted to bar the way to bold educational experimentation." *

"As you perhaps know, my interest in the general high school centers chiefly in the efficiency of that school as a means of general or liberal education. Vocational schools we shall have, eventually, in great number and variety. But the general high school ought to remain chiefly a school giving personal culture and training for citizenship, with opportunity to elect a few studies which promise to have an 'instrumental' or 'prevocational' value in vocational studies or in careers subsequently to be entered upon.

"From this point of view, I feel that the high school should be greatly improved as an agency of general culture and of training for citizenship. It should give the pupil widened vision, enhanced appreciation, and varied understanding, as to the important things of the world in which he lives. My chief complaint against Latin and algebra (both of which hold monopolistic positions in the secondary-school curricula of today) is that they do not, as taught, effectively minister to these ends. It is questionable whether, under present conditions, they can be made to do so." †

"The former theory that that kind of secondary education which was best fitted to prepare pupils for college was also well fitted to educate pupils not so destined is being supplanted by the theory that secondary education has its various functions to perform and higher education must take its origin at the point where the secondary school leaves off." ‡

"The public secondary schools have grown rapidly in numbers and resources. They are no longer essentially stepping stones to college; they represent the continuation of the com-

* George S. Counts, Professor of Education, University of Chicago, in the 26th Yearbook of the National Society for the Study of Education, Part II, p. 86.

† David Samuel Snedden, Professor of Education, Teachers College, Columbia University, "Problems of Secondary Education," p. 228.

‡ Alexander Inglis, Late Professor of Education, Harvard University, "Principles of Secondary Education," p. 314.

mon schools, and their function is to complete the formal education of the vast majority which will never enter institutions of higher learning."*

"In view of the important rôle of secondary education in achieving the objectives essential in American life, it follows that higher institutions of learning are not justified in maintaining entrance requirements and examinations of a character that handicap the secondary school in discharging its proper functions in a democracy."†

From these few excerpts it would appear that the modern high school is to be the "people's college" where the interests of the majority who will never go to college must not be sacrificed for the sake of the few who may.

Let us turn now for a time to a consideration of the modern doctrine of interest. One author has set down in what he calls the "Opposite Poles in Educational Theory," among other statements, the following:

"Theory of Repression: The aim of the curriculum is to prepare for future opportunities and responsibilities. The curriculum necessarily involves much that is distasteful and foreign to the child's immediate interests.

"Theory of Expression: The aim of the curriculum is to stimulate and encourage children to grow by providing for them, through a rich and suggestive environment, activities in which they joyously engage."‡

He states, however, that in his opinion neither of these extreme positions is the one to be accepted.

"All methods, processes, principles, degrees of skill, or facts, as of manipulation, speaking, reading, writing, design, science, geography, history, or civics, should be introduced in response to specific needs or situations which require them.

"To avoid the dangers of arrested mental development, the interest in drills in number, phonetics, language forms, spelling, oral reading, penmanship, drawing, or manipulation

* A. S. Downing & Nicholas Murray Butler in Encyclopedia Britannica, 12th Edition, Vol. 30, p. 936.

† "Cardinal Principles of Secondary Education," Bul. 1918, No. 35, Bureau of Education, p. 19.

‡ Research Bulletin of the National Educational Assn., Vol. III, Nos. 4 and 5, Sept. and Nov., 1925.

should not be permitted to develop to such an extent that these interests become greater than those in the purposeful uses of these mechanical elements." *

"Work in drill processes should not be provided to such an extent at any given time that interest in drill itself becomes wholly separated from the uses which are served by the facts or processes learned. Interest in a means should always be subordinate to interest in the end which it promotes. This helps to prevent what is often called arrested development of capacity for using number." †

"Drill in algebraic manipulation should be limited, particularly in the minor requirement, by the purpose of securing a thorough understanding of important principles and facility in carrying out those processes which are fundamental and of frequent occurrence either in common life or in the subsequent courses that a substantial proportion of the pupils will study." ‡

In discussing the questions in arithmetic given by Horace Mann in the so-called Boston Tests of 1845, the authors comment on one of the problems in the following words:

"What is the square root of 5/9 of 4/5 of 4/7 of 7/9?" They say that problems of this sort are "given solely for the purpose of testing the children's power to juggle figures. Modern educational theory holds that work of this type has less educative value than the meaningful, purposeful use of computational processes as means to ends." §

Developed as a result of the modern emphasis on interest, is the intellectual play theory of education, perhaps nowhere better stated than as follows:

"The foundational training results largely from experiences upon the play-level. The broad range of diversified physical play is the experience which best lays the physical foundations of one's life. It is the diversified activities of social play

* Frederick G. Bonser, Professor of Education, Teachers College, Columbia University, "The Elementary School Curriculum," p. 152.

† Frederick G. Bonser, Professor of Education, Teachers College, Columbia University, "The Elementary School Curriculum," p. 254.

‡ "Reorganization of Mathematics in Secondary Education." A report by the National Committee on Mathematical Requirements, under the Mathematical Association of America, p. 50.

§ Caldwell-Curtis, "Then and Now in Education," p. 69.

which lay the foundations of one's social life. The numerous and diverse types of intellectual play, more than anything else, lay the foundations of all of one's intellectual life. And equally, it is one's æsthetic play activities and experiences which provide the fundamentals of one's æsthetic life. While much of this will be extra-mural, yet the schools will provide abundantly for experiences on the play-level. Since this will be done by teachers, they must be conscious of the play-activities as educational procedure. Those being trained, however, will see it only as play experience. On the foundational level, the children will not be conscious of the specific educational objectives."*

It is difficult to realize that the author can be sincere in this concept of education but the term appears and reappears in his book as for example:

"As fields of intellectual play, neither algebra, demonstrative geometry, nor trigonometry provide centers of growing systems of ideas of any considerable humanistic value. As apperception centers, they do not greatly function."†

Developed from this, is a new concept of the function of mathematics in the educational scheme which I fear is one of the causes of the lack of those "elements of definiteness and thoroughness which are so essential in the training of the engineer."

"We are not prepared to train for the community mathematical functioning until we see that the thing needed primarily is the ability to see and think these hundreds of things in accurate quantitative ways. In the community life, mathematics is not primarily a matter of solving problems, but rather of seeing things in quantitative ways and thinking in quantitative terms. In school life, therefore, mathematics should be primarily not a matter of solving difficult problems, but rather a matter of continuously viewing for many years the quantitative aspects of things, and of thinking in accurate terms."‡

* Franklin Bobbitt, Professor of Educational Administration, University of Chicago, "How to Make a Curriculum," p. 63–64.

† Franklin Bobbitt, Professor of Educational Administration, University of Chicago, "How to Make a Curriculum," p. 161, No. 31.

‡ Franklin Bobbitt, Professor of Educational Administration, University of Chicago, "How to Make a Curriculum," p. 149–150.

"In the general training, the theory of mathematics is to be developed in the minimum measure, actually needful for quantitative thinking. It is accessory, not fundamental.

"Outside of their vocations, almost the only mathematics really used by men and women is applied arithmetic.

"In their general activities, individuals are sometimes concerned with the use of formulae; but rarely with their derivation.

"The consumer uses the inventions of others. He needs to know how to use them; but he need not know all the technical science used by the inventor. This applies to mathematical devices as fully as to clocks or speedometers." *

In other words, the mathematics to be given the vast majority of pupils should be limited to that which they are likely to use in the ordinary affairs of life.

"The mathematics of the basic general training should be that which functions in the non-vocational thought and affairs of men and women; together with that which is common to all vocations.

"That algebra, geometry, or other mathematics, which actually functions, or should function, in the non-vocational affairs of men and women should be included in the basic general training; beyond this, for general education, it should be optional.

"One should have a very thorough mastery of the mathematics involved in one's vocation; but this is to be provided for in one's vocational training." †

When things are included in the educational program for occupational purposes, they will be placed only in the occupational courses, and taken only by those who are consciously taking their occupational training. For example, activity-analyses will show that trigonometry is called for by the activities of the engineer; that it is not called for by the activities of typists, physicians, or milliners; nor by the general activities of persons outside of their occupations. As a consequence, trigonometry will be prescribed as occupational training in the courses for engineers, but not in courses for the other occupations named; nor for general education." Then in italics:

* Franklin Bobbitt, Professor of Educational Administration, University of Chicago, "How to Make a Curriculum," p. 158–159.

† Franklin Bobbitt, Professor of Educational Administration, University of Chicago, "How to Make a Curriculum," p. 158, No. 1, 19, 22.

"Never will a subject be placed in the general training for all persons simply because it is of specialized value for certain occupations." *

Study after study has been made in attempts to learn the mathematical content of various phases of human experience. And article after article has appeared dealing with these studies, as for example, "The mathematics encountered in the general reading of newspapers and periodicals;" "Types of arithmetic needed in certain types of salesmanship;" "A survey of arithmetical problems arising in various occupations;" "Survey of the social and business usage of arithmetic," etc. These studies form the basis for the elimination which appears to be going on in the content of the subject matter presented. This is summarized by a National Commission on Curriculum in the following words:

"Mrs. Gallaway's study deals with the needs of freshmen college girls who take a course in clothing. Obviously, with the basic arithmetic taught and with the evident need at hand, college women will master additional arithmetic as needed. The same statement applies to the study of Williams dealing with the mathematics needed in freshman chemistry. If chemistry calls for more arithmetic, then is the time to teach it. . . . . The findings from these studies point strongly to the following conclusions: (1) That experience must in all cases precede formal work in calculating; (2) that manipulative or calculating skill required is relatively small and not a matter of momentary occurrence to even the busiest of adults; and (3) many processes long retained in the textbooks in arithmetic have practically zero value." †

With the disregard for computational processes, has arisen the necessity for a new kind of instruction. Instead of teaching the fundamental principles, and then teaching the children to make use of these principles in developing a method of attack, my experience in the teaching of mathematics and mechanics in recent years leads me to believe that mathe-

* Franklin Bobbitt, Professor of Educational Administration, University of Chicago, "How to Make a Curriculum," p. 67.

† Department of Superintendence National Commission on Curriculum, Third Yearbook, p. 41.

matical instruction in both grade and high schools is usually conducted along the line of least resistance by showing the pupils how to work type problems. It is true that I cannot find this method justified in modern educational literature but certain warnings against this practice tend to confirm my own opinion.

"The types of persistent error found in handling fractions, such as adding numerators and denominators, suggest that the teaching of fractions results in following a method or in a mechanical procedure, rather than in a clear comprehension of the processes involved." *

"Difficulty in a given problem frequently lies in the fact that a pupil is not able to break the problem up into its various steps and to apprehend the order of the steps. Unless he has ability to analyze problems, his knowledge of arithmetic will be more or less mechanical. The pupil who continually depends upon rules or type problems has attained little mastery of the subject. He should be encouraged to devise solutions of his own. The more insight he has into the relationship involved in a given problem, the freer he will be from mechanical procedure." †

The prevalence of this practice is still further confirmed, as far as I, personally, am concerned, by the constant protest of students against our attempt to compel them to work out processes and methods from fundamental principles.

One of my students expressed his viewpoint to me not long since in the following words:

"Show me how to do the first problem, then I can work them all until I come to one which won't work that way."

In talking with him, he told me that all of his instruction in mathematics had been of that sort. He was the product of one of our large city school systems.

The modern curriculum is designed to give the pupils a basic general training covering most of the activities of life. As an ideal, this concept is doubtless commendable. The way

* Brown & Coffman, "The Teaching of Arithmetic," p. 12.
† Brown & Coffman, "The Teaching of Arithmetic," p. 375.

in which it works out in practice leads, I fear, to an undue respect for superficial knowledge. The attempt to cover too great a field, of necessity, results in but a smattering of information. If this causes the pupils to believe that they really know, what has only been hinted at, and what, perhaps, neither they nor their teachers are prepared to know, how can anything but an undue respect for superficiality result?

To illustrate, not long since, a neighbor's daughter, about thirteen or fourteen years of age, a pupil in the junior high school, came to my door and asked me if I could tell her what a transformer was, how it worked and what it was used for. I did my best. She took notes diligently and when she left me, thanked me and told me she understood it perfectly and that she would be able to tell the class tomorrow. You and I can guess what she really knew about it. She told me afterwards that the teacher complimented her on her discussion of the subject. If that is an example of what our schools are trying to do in the way of training the children throughout all the fields of knowledge, I do not wonder that the material from which we are trying to make engineers is "seriously lacking in those elements of definiteness and thoroughness which are so essential." I fear that the curricula of many of our schools are laid out under the same ideas which furnish the inspiration for the advertisements of Elbert Hubbard's Scrapbook.

I do not care to argue about these tendencies here, for tendencies I certainly feel they are. The excerpts which I have read are from the pens of the leaders of educational thought. They emanate from Teachers College at Columbia, from Harvard and from the University of Chicago. The books from which they are gleaned are texts in numerous colleges of Education. I bought most of them at the bookstore across the street from the Minnesota Campus and was assured that they were being used in classes at that institution.

My purpose here is rather to present to you my findings and ask the question: If these are the modern educational tendencies, do they account for the lack in "those elements of

definiteness and thoroughness which are so essential in the training of an engineer?" Also, if they do; what can we do about it?

A colleague at Minnesota has summarized his experience in the following: "The glaring defects in high school training, as evidenced by tests soon after entrance to the Engineering College and as proved by the many excellently trained exceptions, are: An attitude of mind expressed by 'getting by'—a sort of belief that once a passing grade is received the subject is absolutely finished and ended; too many ideas instead of real knowledge; too much book information learned by rote, neglecting the more important matter between the lines; partly understood fundamental principles; very little training in the practice of judgment; and very little training in initiative in finding out things for themselves."* I would add to this an inability of high school graduates to concentrate and really get down to business and study. It would seem that most of these defects can be charged to the basic theories of modern educators.

What can we do about it? With some of the ideas presented, I do not know that I am in serious disagreement. To compel all to take a college preparatory course because a relatively few expect to go to college, seems unjust. A course in high school mathematics furnishing suitable preparation for an engineering student is of little value to a housewife. Educators tell us that training does not "carry over," which contention seems to be proved in a few cases at least, for my reading has led me to believe that in the case of some authors, if they learned anything of the principles of logic in their study of geometry, it was not carried over into their theories of education. I am not sure, however, of the wisdom of substituting a necessarily superficial acquaintance with many subjects for a fair mastery of a few. We Americans are already too prone to discourse learnedly on what we know the least about, however reluctant we may be to express def-

* F. W. Springer in *The Bulletin of the Minnesota Federation of Architectural and Engineering Societies*, May 1927, p. 18.

inite opinions involving our specialty. If superficiality is to pass for real knowledge among our children, I fear for the scholarship of the future. I fear for the ability of our future engineers, but most of all, I fear for the institutions of government of these United States.

A solution which we are seriously considering is the introduction of a thorough course in preparatory mathematics in freshman year, taught so as to correct as many of the faults due to previous training as possible. Use may be made of what the student has already learned, but during this course, the foundation for definiteness and thoroughness, even in arithmetic must be laid. Also, the ability to devise processes and solutions from fundamental principles must be developed or the graduates of our institutions will be but handbook engineers, unable to cope with the unsolved problems with which they will be confronted, until some one has shown them the way.

I believe that bridging the ever-widening gap between the modern high school and our engineering colleges is the most vital problem confronting us today and if this paper proves to be the means of inspiring this society to attack it, and contributing to its solution, my efforts will not have been in vain.

PSYCHOLOGICAL FACTORS INVOLVED IN THE PRESENTATION OF CLASS MATERIAL.*

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There are many psychological factors involved in the presentation of class material. All are important, but I shall touch briefly upon several: attention, perception, visual aids, the factor of human interest, discussion groups and the like.

When an instructor presents to a class subject-matter of any sort the members of the class attend, at least they are expected to attend. But just what do we mean when we say that they attend? They first settle themselves in their seats, gradually eliminate bodily movements, adjust the head for the optimum in hearing, direct the eyes toward the speaker, or if visual aids are utilized toward the visual aids, fit breathing and all other such functions to the situation in an effort to detract as little as possible from an understanding of the material being presented. The individuals assume a physical-mental alertness, the physical-mental organism adjusts to advantage to allow for an adequate accrual of clear mental content—to enable them to grasp the meaning of the facts set forth. Although we say that we can attend for relatively long periods; several hours if need be, reading a book or studying a problem, speaking strictly psychologically we are able to attend for very short periods, a few seconds at a time and then there is a fluctuation of attention to some other item, or to another aspect of the same item. There is a continuous wavering back and forth from one item to another. As Pillsbury expresses it, attention exhibits itself in pulses. Now one item is clear as mental content, now another.

Attention is dependent upon certain conditions, some ob-

* Presented at the 35th annual meeting of the Society, University of Maine, Orono, June 27–30, 1927.

jective, some subjective, the objective conditions being factors such as size, *e.g.*, a large demonstrational model would be more likely to command attention than a model of average size; intensity; loud sounds; bright lights; contrasts which are decided and definite; novelty, one item differing from the others about it. For our present discussion, however, the subjective conditions of attention are the more important for they are very definitely a function of the individual. We usually think of attention as a free act whereby we turn from one thing to another as we please. We think we choose to attend to one thing rather than to another, and that we choose to attend to it from one angle rather than from another, or that we choose to attend to it to the exclusion of all other things. But very frequently this is not so, there often is no immediately previous desire of which we are conscious, and where such desires are present they have their beginnings in the experience of the individual. The previous experience of the individual, then, determines, in a broad sense, that to which he will attend. In a narrower sense a number of items enter very definitely into this determination. Mental content or ideas immediately preceding any situation play an important part for attention. An object seen in a particular location will be noticed readily a second time where previously there was difficulty in noticing it. This may be well illustrated with puzzle pictures. The concealed animal in a puzzle picture, difficult to discover in the first instance, is found with ease a second time. Why? Because it is attended to in a similar manner; with a definite question in mind, arising from the previous discovery. The intention or purpose in mind at the time is to discover the animal. Similarly after finding the animal if one were asked to look for a face, the face would be found more readily than it would be if one were asked simply to look the picture over and then report upon it. The specific purpose in mind, then, also is an important factor in determining what shall be attended to, the angle from which it shall be attended to, the degree of clearness which the object will assume and the

richness of meaning which will accrue. One sees or hears what one is set to see or hear and, unless especially favored by objective conditions or more general subjective conditions, all that fails to fit in with that particular set goes by practically unheeded. This mental set may be aroused by looking at an object, by a suggestion from something which has previously been seen or by someone asking a question. To illustrate further the importance of this I cite the following: The three sections in elementary psychology at this university have each approximately fifty students. These students enter the Arts and Sciences Building at least three times a week, many of them more often. On the Arts and Sciences Building is a turret or small tower. About the middle of the second semester I asked the students in one of the sections to give a description of the tower. There was a great deal of indefiniteness concerning it. Two individuals only attempted a systematic description, and their descriptions were not at all adequate. A few did not even know that there is a tower there until their attention was directed to the fact, then they admitted that they had seen it a number of times, but their seeing had been little more than a retinal picture at the time, because their mental set or intent was directed toward something other than the tower. Their seeing carried with it a minimum of meaning; the tower was not named as such, it was seen as a mere visual pattern. Had their attention been previously directed toward the tower most of them would have given a fair description of it, and had their attention been previously directed toward it from a particular angle, their descriptions would have been definite and in detail from that particular angle and probably confused from other angles.

The chart just shown illustrates very nicely the effect of attention to one particular phase of an object or another. When one's attention is directed toward sense data in a specific manner meaning accrues to those data quickly and to the point, when one's attention is not directed to sense data in a particular manner there is likely to be confusion and

delay before specific meaning becomes apparent, and then the meaning accruing may be quite meagre and not the meaning intended. It is fair to assume, therefore, that in the presentation of subject-matter in the class-room care should be taken, especially in an elementary course where the students lack background, to set forth the main points in very definite form, clear and simple in exposition, to promote a thorough understanding of the subject, for on this understanding of the fundamentals all future accretions depend. A student may attend to subject-matter from one angle and completely miss its significance when the instructor is treating it from a slightly different angle, and the student who fails to grasp thoroughly the fundamentals of any subject can hardly be expected, later, to have a definite and adequate mental set or intent toward a more advanced presentation of the subject in question. He will not approach the subject with specific questions in mind or with a questioning attitude, which amounts to the same thing, and if he lacks this questioning attitude he has a minimum rather than a maximum of interest, for interest is heightened by a question which is to be answered or by a problem which is to be solved, especially when the question or the problem is, to all appearances, of one's own instigation. Thus, we find that the meaning which accrues to subject-matter presented, depends very largely upon attention; the way in which we attend; the angle from which we attend; the questions we have in mind when we attend; the degree of interest present when we attend, and the like.

In the actual accrual of meaning to sense data we have perception, and here past experience is of tremendous importance, for the interpretation placed upon sense data is dependent almost in total upon past experience. Perception is the fusion of these sense data and memories. When subject-matter is presented we have numerous sensations—patterns of sensations or impressions—and these patterns of sensations have meaning for us according to the richness of our experience in relation to the subject-matter being presented, and in no other way. If our past experience is

meager, the interpretation we place upon the subject-matter will be threadbare; if our background of experience embodies data which are erroneous, our interpretation will be incorrect; only in so far as our background of experience is rich in facts, definitely organized, and ready for immediate use, can new or partially new data be fused to embody adequate meaning.

In the process of perception we ignore some items, we subtract some items and we add some items; we never accept the sense data as they stand before us or are presented to us. Just as in the process of learning to typewrite certain cues finally stand for a whole sentence, to allow that sentence to be written off with a bare glance at the copy, so also in perception certain cues come to stand for the meaning of a total situation; and, again, just as in the process of learning to typewrite it is essential that errors be eliminated in the initial learning, to insure later accuracy, in the initial perceiving, if I may be permitted to phrase it in this way, errors should be eliminated for the sake of future accuracy. If errors have been built in, in the process of learning to typewrite they show on the paper visibly and the instructor makes it his business to have the learning remechanized correctly. In the presentation of subject-matter in the class-room there is no direct method of viewing errors which build themselves into a student's background of experience, but just because of this fact it is the more important that subject-matter be presented accurately, if necessary repeated from different angles, and that it be presented with a specific end in view. Not until basic facts are mechanized to the extent that they have become habitual reactions are they really available at all times, and when not available in this way the student is continuously finding himself in the predicament of being unable to assimilate the subject matter which is presented. Thus, from the standpoint of perception as well as from the standpoint of attention it is imperative, especially in an elementary course, that the subject-matter presented be set forth with exactitude, with definiteness and with a specific end in

view, and not presented merely as so much material belonging to a certain course.

Let us now view the question briefly from the standpoint of the subject-matter. Shall aids be utilized in its presentation? If so what form shall the aids take? We know that the visual modality, the visual sense, predominates over the other modalities, and on the basis of this knowledge it has been advocated that subject-matter, to be most effective, should be presented visually, some have gone so far as to intimate that material may be presented adequately, visually, without accompanying verbal instruction. There has been some very interesting experimentation in this direction, the results of which are worth noting. The study I have particularly in mind is published in book form under the title "Visual Education," edited by Frank N. Freeman. It is a rather comprehensive study consisting of a number of different experiments which were conducted in the schools of several large cities. It takes into consideration motion pictures, slides, stereographs, charts, maps, models, and the like, individually and in combination with verbal instruction. Control classes were conducted for the purpose of checking the results, in which these aids were not utilized. I shall touch briefly upon some of these results.

In regard to the effectiveness of verbal instruction as contrasted with the various forms of concrete experience represented in visual education, the results indicate that motion pictures may be of considerable value in presenting certain definite and concrete kinds of experience, but the results give no support to the belief that pictures may be substituted for language. If any such substitution were attempted the past experience of the individual would need very definitely to be taken into consideration. If an adequate background of experience were at hand pictures might be substituted for verbal instruction.

The comparison of the motion picture film with other visual aids such as slides, stereographs, models and the like, as a means of informational instruction, indicates that the motion

picture is superior within a restricted range of subjects, and that outside this range of subjects the older devices are just as effective or more effective than motion pictures. The motion picture has merit in cases in which the understanding of the action of an object requires that it be shown in motion, and also, though not so definitely indicated by the results, it has merit from the fact that motion makes objects attractive and as a result commands close attention which prompts to better learning. The still picture, however, has this advantage: it permits analysis and provides the opportunity for a more active study attitude on the part of the student. The still picture also gives a greater opportunity for the instructor to exert a personal influence and stimulate the class to active thought.

In the teaching of science, demonstration by the instructor is superior to the motion picture. The instructor here has the advantage of being able to watch the students and vary the presentation, amplifying it where necessary.

In teaching how to make or to do something, demonstration, where it can be advantageously carried out, is superior to the film, but the film is superior to methods other than demonstration.

It does not appear that motion pictures are of outstanding and unparalleled value as means of awakening interest in a subject or of stimulating activity, in comparison with advanced modern methods of instruction.

Each of the common forms of instruction which employ visual aids has some advantage, and there are circumstances under which it it is the best form to use *e.g.*, slides are very effective where analysis is necessary, and where distance and the third dimension are important, as in objects of intricate construction, stereographs are invaluable as they do full justice to the third dimension; and they are relatively inexpensive.

The particular province of motion pictures is that of exhibiting moving objects where the analysis of motion is the important factor.

The superior effectiveness of the instructor as contrasted with any merely physical device is indicated repeatedly in the results of the investigation.

One other important item is brought out in the results of the investigation, the fact that in the use of any visual aid whatsoever care should be taken to encourage initiative and an intellectually active attitude. The mere presentation of material does not guarantee that it shall become part of the mental machinery of any student. In fact visual aids improperly used may produce a passive attitude rather than an attitude of active inquiry.

On the basis of our psychological knowledge of class-room relationships, and on the basis of the results of investigation we can state with assurance that no device can take the place of the instructor and that aids, at best, be they ever so elaborate, are merely aids, which, in the hands of an instructor shall be utilized to advantage according to his ability. If the instructor has his subject well in hand, has a fair command of language, and is resourceful he can utilize almost any aid to advantage. Thus, we find, that in the presentation of the subject-matter, the instructor is the focal point.

There is still another important factor in the presentation of subject-matter and that is what may be termed the learning morale of the class. The intellectual standing of the class depends upon this learning morale just as surely as the military standing of an army depends upon its fighting morale, and the building up of this morale is just as necessary as the building of morale in the army. It involves many factors which never appear on the surface. To be sure some people are destined to mediocrity by nature, but many others are mediocre because of their attitude toward learning and study. On account of long standing habits, campus tradition, the idea of merely "getting by" and a host of other such factors they float along exerting themselves to the extent of securing only a passing grade. Some members of a class are always hyper-critical, seeking every opportunity to discuss the instructor in an unfavorable light, his physical appearance, his

speech, his mannerisms, his dress, his method of presenting his data; this kind of discussion between students is detrimental in its effects. High grade students may become mental loafers because of the fact that the course is not keyed to their speed, low grade students may become discouraged because they are unable to keep the pace, and the conscientious student may be unable to stand the strain of wading through a mass of collateral reading. The different attitudes of the various kinds of individuals in a class do not long confine themselves to the members of the class, but percolate throughout the campus, where they are integrated into a generic attitude which finally exerts its influence from year to year, for good or for ill. The instructor may have his material well in hand and be able to present it adequately, but the generic attitude of the class and campus toward him and his subject may be detrimental to the intellectual morale of the class.

If we dig deeply enough we may find that a considerable number in any large class are inhibited in their learning because of fears which they entertain. An individual may stammer or stutter and his stammering may be looked upon as only a habit, but if we gain his confidence and probe a little we may find that the stammering is his reaction to a general fear attitude. Even with people who give no outward sign of the fact, except perhaps a lower grade than they should earn, or perhaps a certain bashfulness, fear attitudes often are the inhibiting factors detrimental to learning. Lack of confidence in their ability to succeed, in certain subjects, often keeps students from accomplishing what they should accomplish. Especially is this true in examinations. When this attitude develops to an inferiority complex it may be detrimental to the point of being pathological. I had one such case this year. He eternally stated as he went out from each examination that he had failed, and he continuously said that he could not possibly understand the subject. Once when I assigned the class a chapter in a book, and required a paper to be written, he failed to turn in his paper. I reported his rank at mid-semester as tentative and again asked him for

his paper. He said: "Do I really have to write that report?" "Yes," I said. He replied: "I don't understand it at all and it's no use me trying to write it. I thought you would give me an F and let it go at that." He was so afraid that he could not accomplish it satisfactorily that he was willing to accept an F rather than tackle the paper. But I insisted that he do it, which he eventually did, turning in a much better paper than some other members of the class. He was perfectly honest about his statement of inability too. He lacks what a considerable number of individuals have to the extreme—the ability to bluff.

Again, the ATTITUDE of the instructor must be taken into consideration and this is perhaps of greater importance than any other single factor. What is the instructor's attitude toward the class as a whole and toward the individual members of the class in particular? Is the instructor primarily teaching a subject or is he primarily interested in developing individuals? These and many other questions immediately arise in a discussion of the attitude of the instructor. We can merely scratch the surface here.

If the instructor is primarily interested in teaching a subject what are we likely to find? In all probability the facts will be set forth with accuracy, and a relatively high standard will be required. This is laudable, we need more of it than we have. Class quizzes, prelims, and final examinations will be given due prominence, and this is somewhat necessary under the present system of mass production. The subject-matter in general will be well handled (I speak of course of the instructor who has a broad background in his subject and who is fluent). But there is likely to be a rigidity about the whole procedure which leaves the subject cold. The facts will likely be set forth in a manner which leaves a gap between instructor and students—a gap which is very difficult to fill. At the close of the class period, except for the few who will dare "to beard the lion in his den" the students will feel that their dealings with the instructor are over until the next class period. Few will consider themselves free to ask questions be-

cause of the rigidity of the atmosphere, if they fail to understand the facts that have been presented. Questions may display their ignorance, and a display of ignorance may mean incrimination; so they carry on an intellectual hide and seek (until an examination is set) with the instructor rather than face their own shortcomings in the subject. They build up a process of rationalization in regard to the things in which their understanding is hazy, rather than face the situation that their understanding of the subject is hazy, and go to the instructor to be set right.

On the other hand, if the instructor is primarily interested in developing individuals he will embody in his presentation of the subject-matter an attitude of human interest which will tend to bridge the gap that exists between students and instructor. Students will feel freer to ask questions, and feeling free to ask questions, questions will more readily arise in the minds of the students. There will be a friendlier feeling between students and instructor. The students will be less likely to feel, when they exhibit their ignorance by asking for information, that they are incriminating themselves. This does not mean that the standard of scholarship will be lowered; in all probability it will be raised; it should be, for when students have their questions answered they thereby gain a better understanding of the subject. It should also mean that the instructor will gain a better understanding of the students' grasp of the subject, for when students step into an instructor's office seeking enlightenment there are usually a number of questions back and forth. We continuously see the kind of thing of which I speak in every-day life. We meet certain of our acquaintances and we *freeze* immediately, our whole attitude becomes *strictly formal*, we speak no more than is necessary and we most certainly allow no information to slip out which might incriminate us. We meet other acquaintances and we are immediately at ease, we speak on any subject freely, our inhibitions disappear. We know that they are our friends, that even if they know our shortcomings they will not take undue advantage of them, though they require us to

pay them what we may owe them. We are likely to accept the word of the latter type much more readily than the former for we know that there exists no ulterior motive. They are interested in our welfare as we are interested in theirs and, provided we do not abuse their interest in us, they are willing to go out of their way to help us. Now, just as we are more at ease in the presence of our acquaintances who possess this quality of human interest, so are students more at ease in the presence of instructors who possess it. The rigidity disappears and a certain dignified informality takes its place, an atmosphere much more conducive to true learning.

The tradition of the classroom is formality and a certain degree of formality will continue to exist, but the extreme formality which delimits the students' expression is detrimental yet it is difficult to change. Students have become so habituated to listening and they usually are so afraid of making false moves in the presence of the instructor that they often prefer to look wise and to say nothing. This attitude can, however, be changed by dividing a class into small groups and conducting discussion periods. Even in the small groups it may at first be difficult to pry the students loose and get them to engage in free discussion, but if questions are asked, tactfully, and the students understand that there are no penalties for incorrect answers, eventually they will talk. This I know for I have tried it, but it took a whole semester for the members of the class to really fully comprehend the fact that the discussion groups carried no penalties for errors made. This method necessarily adds several hours each week to an instructor's load, especially if it is a large class that has to be sectioned, but I presume that in whatsoever capacity one deals with humans one will be called upon for hours beyond those which show on paper.

At the end of the academic year, in the final examination, I put the following question to one of the sections in psycholgy: Have the bi-weekly discussion groups been of benefit to you and are they worth continuing? Have you any suggestions for their improvement? The students were notified

that this question was entirely gratuitous, that no answer was compulsory. There were fifty students in the class; forty-two stated that the discussion groups were of benefit and that they should be continued. One member of the class said that he had received no benefit from the discussion periods. Seven members returned no answer. The suggestions which permeated the replies were that the discussion periods should be held every week instead of every two weeks, and that the groups should be kept as small as possible. I shall read three representative replies in order to present the students' point of view.

"The bi-weekly discussion groups have been of value to me for the reason that much of the material I hadn't clearly in mind was made so in hearing the material repeated in those groups, and also, things I thought I knew, I found I knew only partly when called upon to recite, and I learned them entirely in failing to give the complete answer.

"The first semester I was in a large group and I got less out of it than in the second semester's smaller group where there was more chance for discussion and individual recitation. The only suggestion I would make is to have them as small as possible."

"In my opinion the bi-weekly discussion groups have been of great value in this course. By reviewing the subject in an informal way, by asking questions on points not fully understood in class, and by being asked questions in a manner not designed to 'catch' a person but to fix the idea in his mind was a great aid to me. . . . I believe that if every one in the class could be brought into the discussion and get more into the spirit of it by dispelling the fear element of showing their ignorance, the total good might be increased. By all means continue the discussion groups."

"I think the bi-weekly discussion groups have been a help as they give the student a chance to clear up any difficulties which he may have with the material, and being quizzed helps to tie down the material which has been gone over. They have helped me in that I have learned to go back to the source of a question and try to figure it out more logically than I used to.

"The only criticism I have to make of them is that they

do not come often enough. If they came once a week there would be less material to cover and there would be more time for discussion.''

These statements show us that students appreciate the opportunity of discussing, in an informal way, material which has been presented in the regular class periods, and they also indicate that the students are definitely benefited by such discussions. They point to the fact that small groups stimulate discussion more than large groups do, and they indicate, further, that they tend to stimulate thinking in place of mere memorization of material for examinations; and thinking is what we need more than any other one thing, and is something of which we get relatively little in formal classroom presentations.

Many other factors could be considered but those cited will indicate the opportunities for the instructor beyond the actual presentation of facts.

In conclusion let me state that the psychological factors involved in the presentation of class material or subject-matter are of such importance that their neglect or their definite consideration may result in intellectual stagnation or in constructive thinking, for a considerable percentage of any class.

1. Burnham, William H. The Normal Mind. N. Y., D. Appleton and Co. 1924.
2. Dickinson, C. A. Experience and Visual Perception. Offprint, Am. J. Psych., July, 1926.
3. Freeman, Frank N. Visual Education. U. of Chicago Press.
4. Pillsbury, W. B. The Fundamentals of Psychology. N. Y., The Macmillan Co. 1924.

DISCUSSION.

A. H. Fuller: These papers have been too interesting to permit of any hesitation in breaking the ice in the discussion. In attempting to break the ice, I realize that a thorough discussion would run into hours, rather than minutes, and I shall refer only to a few things which particularly appeal to me, the first of which is the pedagogy in Professor Comstock's paper. I hope every teacher in the engineering colleges will read it thoughtfully. There is surely meat for everyone.

Professor Comstock's reference to the high school work reminded me of a couple of extracts from one of the General Committee reports, which were submitted to the Society a couple of years ago. Those extracts are: first, that high school work has been deteriorating over a period of ten years; and second, that one reason for the deterioration was that the high school methods were devolving into the solving of easy problems by imitative methods. Whether those are the facts or not, it opens a question for us as to what we are to do with the high school graduate as he comes to college. We know the high school people claim they are training primarily for citizenship and we also know that they are pretty well set in their way. Any attempt we could make to change the work in the high schools would proceed very, very slowly. Our immediate problem is to take the product as we get it and develop it the best we can. The important factor is to bring these people from "solving easy problems by imitative methods" to learning to think and to think from a basis of engineering fundamentals. That again raises the old question as to what are the fundamentals of engineering.

The study which has been given by Professor Curtis this afternoon of the time spent on mechanics at the University of Iowa is very interesting. The interest would be even greater if he would give us some idea of the nature of those problems so as to see which ones the men handled to the best advantage.

Professor Comstock has covered that point well in pointing out the pedagogical value of selecting the problems in the right way.

Now, while this very interesting study has been going on in Iowa City, we at the sister institution in Ames have been going at it in a different way. For our year's study in the engineering faculty, we have attempted to find out for ourselves what are the fundamentals in some of the subjects we are teaching. Through the general engineering faculty, and through committee work, we have already tackled mechanics and calculus. Through the Civil Engineering faculty, we have tackled materials. Rather well-condensed committee reports are under way in all of those subjects. We have, as yet, no conclusions to announce, except that the study is going to give each one of us a much clearer conception of the things which need most emphasis in these subjects. Professor Comstock has said this afternoon that he thought much of the work in arithmetic could be eliminated to good advantage. Perhaps some of the work in mechanics and in calculus can be eliminated, and thus make it possible to place greater emphasis on more important portions. We are now attempting to make the study. If it proves to be interesting, we will be glad to report it next year.

W. E. Wickenden: While Professor Comstock has been making his admirable summary of the general educational situation I have detected a good many men taking notes. I suspect that many were taking down references to the publication he cited. May I suggest that you add to the list you have been making the Bulletin which has just been issued by the Division of Educational Inquiry of the Carnegie Foundation for the Advancement of Teaching under the title "The Quality of the Educational Process in the United States and in Europe." The author of this Bulletin is Dr. W. S. Learned and I believe that it is being given free circulation. Every man who has been stirred by the current trends which have been discussed this afternoon will read it with both interest and profit and will find delight in the admirable style of presentation.

Dr. Learned sets forth the results of a prolonged study of secondary education, bringing out with striking emphasis the impossibility of reconciling the so-called socializing or democratizing tendencies now at work in secondary education with the laying of adequate foundations for intellectual careers. The Bulletin seems to indicate that the Carnegie Foundation for the Advancement of Teaching will largely direct its efforts to interesting the American people in the development of a dual system of secondary education, so that one of these fundamental and necessary ends will not be sacrificed to the other. I commend this report to you most highly. Address your request to the Carnegie Foundation for the Advancement of Teaching, 522 Fifth Avenue, New York.

Wm. T. Magruder: I was particularly interested in that portion of Professor Comstock's valuable paper where he spoke about the doctrine of interest. Some years ago, some people professed to have no interest in things which had any utilitarian value. It was once the fad to decry scientific discoveries which were of practical utility. Now the applications of chemistry and physics interest people more than do the principles of those sciences. English must be useful and not necessarily literary. The pendulum seems to have swung to the other extreme and Mr. Hoover finds that he has to call the attention of the engineering world to the need for more research in pure science.

The present tendency in engineering education seems to be vocational, rather than professional; to be of the handbook type, rather than thorough; and imitative, rather than original. Not a few employers are looking to the engineering colleges for young men to fill positions which could be as well filled by a trade-school graduate, and are getting them because positions in the trades and in sales-work pay more at first than do those in the professions.

Excessive emphasis on the applications of knowledge have obsessed some of the colleges and public schools. We are now expected to teach boys and girls the things in which they are interested. If we can not interest them, we are politely told

that the fault is ours. The challenge has been issued by a certain class of school-men that, if a "student is not doing satisfactory work, we must find a course which will educate this individual and stimulate him to his best efforts, however feeble they may be." That "public institutions should keep the road of educational opportunity open as long as the student *wishes* to pursue it." This means never failing a man out of school or college, no matter how bad his record may be, but to continue to assist him to waste his parents' money while he is repeating special courses in "Campus-Lab." activities, loafing, and the like, while being a drag on the progress of the other members of his class.

The modern occupational student has to go out and take a smoke at the end of each fifty-minute period. To keep him continuously in the laboratory, or the drawing room, for two hours would be wrong, and for four hours would be cruel, such is the nervous temperament of many of our students today! Yet, the week after Commencement, he is expected to take up his life's work and put in four hours of uninterrupted work for his employer.

As to the doctrine of activities, some of us and of our students, I fear, have activities on the brain. Athletics now have to divide the honors with other activities, all of which may be very useful and beneficial when pursued in moderation. Even the Student Branches of our national engineering societies can be overworked and to excess.

There is such a thing as being intemperate in the pursuit of even good things, and education is not an exception to this rule. The best traveling is to be found in the middle of the roadway. The pitfalls, ditches, and miry places are on either side. As engineering teachers, we should watch both sides of the road and should strive to teach the sciences by using their applications as illustrations of both their principles and of their usefulness.

T. F. Garner: I should like to approach Mr. Comstock's address somewhat cautiously.

His subject contained the word "tendencies." From his

talk I inferred that he desired the word "tendencies" to mean largely modern educational theory. That was the impression I gained because of his citation of various men peculiarly interested in educational theory; for example, the late Professor Alexander English of Harvard and Professor Bobbitt of the University of Chicago.

I was somewhat at sea when he concluded his address with the question "What can we do about it?" I was unable to perceive the exact relation between modern educational theory as such and certain high school results that we are getting, particularly in reference to training for engineering courses.

I believe there is a marked difference between educational theory of the modern type and educational teaching of the modern type. Our theory may be of the very highest nature and our teaching may not necessarily coincide with that theory at all.

It seems to me that Mr. Comstock's paper has been presenting largely methods of teaching and educational theory without clearly differentiating the two. I think we ought to go back for a moment and try to see what educational theory of the modern type is attempting, what it is all about, see what specific bearing that has on the high school as it exists, and then apply the situation which we find to the demands which the engineering college may logically try to make upon that school.

Now let us take modern educational theory and see what it is about. If we were to summarize the whole range of educational psychology of to-day into as brief a statement as possible we should omit many statements about interest, attention, apperception, and so forth. We should come to a basic statement which might be represented on the blackboard as follows: There would be an arrow in the middle of the blackboard pointing to the right. To the left of that arrow there would be a large letter of the alphabet called S. To the right of that arrow there would be the letter R.

All this simply means that we have to take human nature as it is. We have our children in elementary schools and in

secondary schools handed to us from their parents and not from a carefully organized pedagogical—I was about to say machine for brooding chickens—but that is not precisely what I mean.

That arrow represents the human nature with which we have to work. The R represents very largely what takes place as a result of things operating upon that arrow, and that S on the lefthand side represents the various things that play upon that arrow—the stimuli that influence the child as it goes on up through student days. Then, we know basic nature: what it is and how it develops. The next problem that we face from the standpoint of our high school system, even from the standpoint of our home system and our elementary school system—the chief thing we face, is what shall become of this human being that is now one minute or ten years old. That is the problem the parent faces from the time the child is one second old until the parent has passed out of this particular world's existence.

Modern educational theorists have been speculating as to where this human being is headed. They have worked at various theories about getting him there. How many students in our high schools are headed in the direction of the engineering profession? I inferred from the implications of Mr. Comstock's paper that he meant to say the high school is at fault in not giving to the engineering school young men adequately prepared to do the job that the engineering school logically has the right to demand. Is that true or is it not? Undoubtedly it is true to a large extent. Suppose we analyze the purpose of a high school education. There is only one conceivable purpose—that is not quite fair—I will put it another way. There is one focal point, one center, which any education must have and that is the student himself. Education must be child-centered, man-centered, woman-centered. It is not vocation-centered or institution-centered. We have no right to say to high schools that they should equip men for this particular institution or that. What we have to do is to analyze the constituency of our high schools and see what the

finished product is. What is the finished product of the high school? Some high school products go to schools of theology, some to schools of liberal arts, some to dental schools, some to schools of law. Many never again after leaving high school step inside of an educational institution.

Suppose we accept the principle that it is the job of the high school to prepare certain students for admission to the schools of engineering. What can be done? Certain schools can meet the situation. There are certain technical high schools which are designed to do that thing. However we have no right to ask a high school of commerce to prepare students for admission to engineering schools. Take the small country high schools. How many students from any particular country high school does any college get? Maybe just one. Do we have the right to ask the small rural high school to modify its curriculum so as to equip the student to go to engineering schools unless the material he studies has specific value to him and has also a widespread general value for him. I believe it is unjust. However, in the case of our larger high schools which provide elective courses we do have the right to urge that adequate preparation subjects for professional college study be offered as electives. It is fair for the high school to say to its students: "On the basis of interest you have the right to take these courses. You have that right because of the interest you have in a life profession. If you are going to be an engineer, you have the right to elect these studies." But to say that all high schools should make this provision is not quite fair.

Let us turn in another direction for a moment and consider the problem of teaching. I am not certain that the men who were cited are responsible for the teaching conditions discussed in Mr. Comstock's paper. I believe we must conceive educational theory to be generally somewhat ahead of educational practice. Are the men who uphold theories of education responsible for the conditions under which instructors teach? I do not believe so. The fact that educators urge the elimination of arithmetic or algebra does not also say, "Scatter the field of concentration."

The statement that high schools turn out students who are not able to concentrate or to be original I should answer in this way: Take students as life ordinarily is lived, not in an ideal state but as students, as children. From a few moments after they are born up to about the time they die the one predominating fact of life is: "Accept what I say to you." Parents say to the child, "Believe what I say." The minister says, "Believe what I say." The pre-school teacher says, "Believe what I say." The grammar school teachers proclaim, "Believe what I say." The high school teachers exclaim, "Believe what I say." Almost every textbook written demands, "Swallow what I say." The textbook is simply an oral lecture or series of lectures put into printed form. Almost everything up to the college level is practically a question of the student's swallowing what is said. He is not made to think for himself. Everything is predigested for him and concentration is not his chief problem. How can we, then, expect students to concentrate and be original when their whole existence is worked out in that way?

E. H. Comstock: I do not know whether or not the last speaker is familiar with modern youth. Even though we say it, I do not believe the modern youth accepts it as we say it.

I fear the last speaker missed some of the things I read. I read, "With some of the ideas presented, I do not know that I am in serious disagreement. To compel all to take a college preparatory course because a relatively few expect to go to college does seem unjust. A course in high school mathematics furnishing suitable preparation for an engineering student is of little value to a housewife." I fail to see how he could get the implication which he drew from this. Another statement which I made was that, "I am not sure, however, of the wisdom of substituting a necessarily superficial acquaintance with many subjects for a fair mastery of a few."

I know that a great many children in Minneapolis are getting a smattering of many subjects. I think many of you here who come in contact with freshmen in the University will agree with me that there are a comparatively small number of

our students who have a fair mastery of a few subjects but they do have an awful smattering of a large number of subjects.

This paper is not simply the result of having read a few books on education. It comes also as a result of talking with students, talking with parents and talking with teachers and educators. Dean Leland and I have sat on committees with some of our educational colleagues at Minnesota and arguments advanced by them bear out many of the quotations I have read in this paper.

I fear another speaker mistook a quotation for an expression of my idea. I do feel that our arithmetic in the public schools at the present time is very, very poorly taught. I think the pupils ought to have more arithmetic, whether they are going to be housewives, salesmen or whatever field they may be going into.

The following happened in the College of Engineering at Minnesota and was called to my attention by one of my colleagues: A student was asked to reduce $^{16}/_{64}$ which he did by crossing out the two sixes: $1/4$. The answer is correct of course and he argued for the correctness of the method on the basis of the correctness of his answer.

For ten years or so I have taught freshman algebra. I want to get acquainted with the boys when they come to the school. I have a few catch questions up my sleeve; they are not bad ones but they lead to a result something like this:

$$\frac{a+b}{a},$$

and I say, "be sure your answer is in its simplest form." A few years ago, I occasionally got this for an answer:

$$\frac{a+b}{a}.$$

Of late years, if there is anything in the numerator that looks like anything in the denominator, the students will cross it

out; it does not even make a difference whether it is an exponent. Here is what one boy did:

$$\frac{a+b}{a-b}.$$

He canceled his a's and b's and left the plus over the minus. I said, "Why did you not cancel the two horizontal lines and then your answer would be 1?"

COLLEGE NOTES.

Case School of Applied Science.—To meet a need which exists in all colleges for something to be done to insure the success of a new student in meeting the requirements of the departments, and in fitting the student for the proper application of what he learns, Case School of Applied Science has inaugurated a plan whereby Professor P. J. Zimmers, Professor of Education, will give a series of lectures on "How to Study."

Professor Zimmers has a wealth of background for his work, for he was Superintendent of Schools in Wisconsin for fourteen years, and before coming to Case he was Extension Director for the University of Wisconsin in the Milwaukee District. He is author of a book, "How to Study," which has reached the fifth edition.

Professor Zimmers holds to the opinion that education does not consist of "stuffing" ourselves with a mass of learning. He has disagreed with Professor Lowell of Harvard, who recently has stirred the meetings of the National Education Association in Boston with severe criticism of our public schools. Professor Zimmers says, "In spite of the criticisms of our American public schools and colleges, they are doing a splendid work."

He has pointed out that many high schools fail to prepare students for college in mathematics and English. Figures show that among 8,728 students admitted to 52 institutions, 17 per cent were conditioned and failures in mathematics reached 68 per cent.

It is the firm conviction of Professor Zimmers that the prime reason for high school students failing when they meet college requirements is that they do not know how to study. Case is able to graduate about 40 per cent in the normal period of four years. Among 38 institutions in the United States and Canada it is found that but 28 per cent of those admitted are able to graduate at the normal period.

The most important point in Professor Zimmer's views is "a happy childhood for all our children, a school life of activity, and a thorough preparation for life's demands are being effectively given by our high schools and colleges." If this is a reality, then high schools do more than prepare for college entrance requirements.

Case students must learn how to assimilate facts, but more how to apply those facts in the sciences and in engineering practice. Theirs is a problem of being analytical, of seeing things from sources, and of seeing things clearly.

University of Kansas.—Professor F. Ellis Johnson has been made head of the department of Electrical Engineering because of the change of Professor George C. Shaad to the position of Dean of the School. Professor Johnson has been connected with the Electrical department of this School since 1915.

Professor A. H. Sluss has been appointed acting chairman of the Mechanical Engineering department. The work of Industrial Engineering is also handled by this department. Professor Sluss entered the department of Mechanical Engineering in 1908 and has held the position of Professor of Mechanical Engineering since 1922.

Professor F. M. Dawson, professor of Hydraulics, who has been devoting a large portion of his time to the position of Dean of Men for the past eighteen months, has, upon the return of Dean John R. Dyer, returned to the Engineering School for full-time work in his special field.

One of the activities of the associated engineering societies of the School for this year is the arranging for the presentation of a series of papers on the general subject of Electrical Communication. This program is for the engineering student body alone with the exception of the lectures by Hamlin Garland and Dr. Ives, which are open to the public. Dr. Ives's talk on Television will be the first lecture of an engineering nature to be given in the new University Auditorium.

The Kansas State Agricultural College has asked the Chemical Engineering Department of the Ohio State University for cooperation to develop their courses in Industrial Chemistry and Chemical Engineering. Mr. Wilson F. Brown, instructor in Chemical Engineering at Ohio State for the last three years, was therefore released from his work in the Chemical Engineering Department at Ohio State University for this service and accepted an Associate Professorship at the Kansas college.

SECTIONS AND BRANCHES.

The **Colorado Branch** held its first meeting for this school year at four o'clock, October 19, in Engineering Building No. 1. The meeting was primarily a reception for the faculty and their families. Professor John A Hunter had charge of the program for the children, and he entertained them by reciting a monologue and showing several films. Dancing provided the chief form of amusement for the faculty members and their wives. Refreshments were served, and the meeting ended at six o'clock.

The second meeting was held January 12 at six o'clock. An oyster supper was served under the direction of Professor C. A. Hutchinson. The meal was followed by a discussion of the subject "Readmission." No attempt was made to decide upon any action. The purpose of the discussion was to learn the views of the faculty regarding the readmission of students.

Professor Hutchinson presided, and he called first upon Dean H. S. Evans, of the Engineering College, who gave a brief history of the handling of readmission in the University; then upon Dean O. C. Lester, of the Graduate School, who spoke about the student attitude towards readmission; then upon Professor P. G. Worcester, dean of men, who compared the readmission regulations of this University with those of other universities. Others were then given an opportunity to express their views. The trend of the discussion indicated that the faculty were agreed that all freshmen who failed to pass the required number of hours the first time should be readmitted. With the upper classmen, the members thought that the rules of the University should be strictly followed. Professor Hunter, representing the Readmission Committee, pointed out that the difficulties encountered in readmission were caused primarily by the system of mass education. He believed that the freshmen, especially, should be dealt with

leniently and that they should be given ample time to adjust themselves to university requirements. Dean Lester stated that the freshmen who failed the first quarter should be allowed two quarters of probation so that they could complete the school year.

WAINO S. NYLAND,
Secretary.

BOOK REVIEWS.

Introductory Textbook of Electrical Engineering. J. R. Benton. Published by Ginn & Co. 1928.

This book presents as many of the fundamentals of electrical equipment as is possible in a minimum of space. Each chapter is supplemented with problems the answers to which are printed at the back of the book (except Chapter 13). There are twenty-three chapters and a total of one hundred and thirty-two problems.

The book should find application in non-electrical courses in many of our engineering schools because so much is included in so short a space. R. C. G.

English for Engineers. S. A. Harbarger, Assistant Professor of English, The Ohio State University. Published by McGraw-Hill Book Company, Inc., New York. 290 pages. Numerous illustrations. $2.00.

This is a second edition of a well-known text written specifically for engineering students. Many new and valuable illustrative examples have been added in the text. In the appendix are given a number of very valuable suggestions for practice writing, which should form an excellent aid in the use of the text. It has been the aim of the author to emphasize the importance of clear concise expression of ideas along engineering lines and to aid the engineering student to better use his technical data.

The book leads the student to a closer study of such subjects as letters of application for a position, the wording of telegrams, the composition of abstracts of technical papers, the preparation of engineering reports and papers to be presented before technical societies, and a wealth of other legitimate applications.

The first edition of the book has been accepted as an excellent addition to engineering curricula. The second edition is even more valuable than the first.

J. W. H.